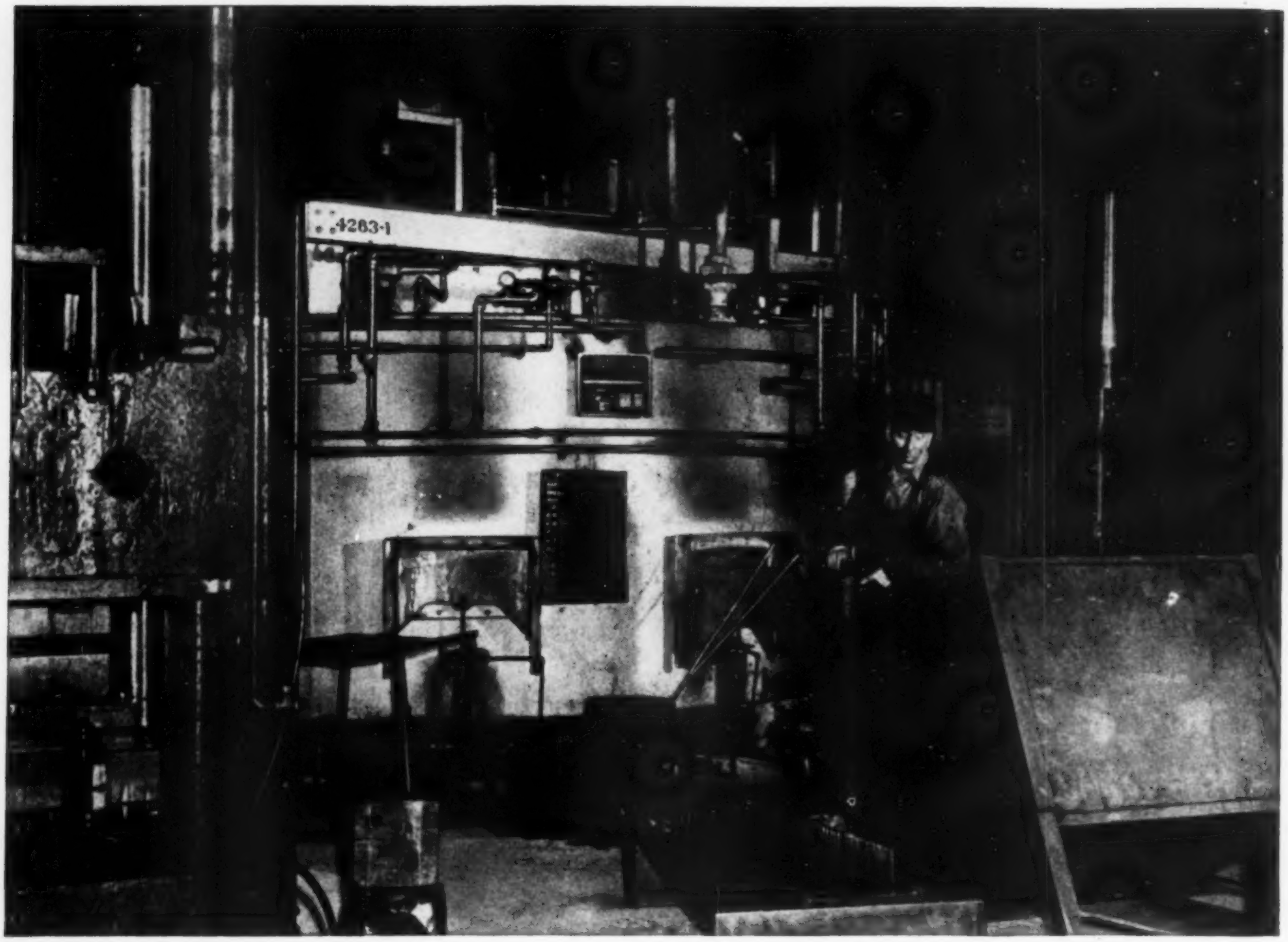

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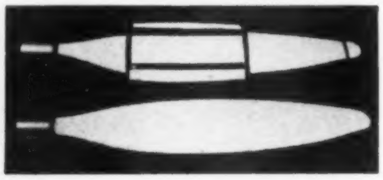
The Key to Precision Forging



If your operations include the forging of relatively thin parts which must be held to close dimensional tolerances and have unusually smooth surfaces, you will be interested in the unusual requirements of these forged propeller blade parts.

MATERIAL: SAE 4340 Steel.

HOT FORGING OPERATIONS: 65 total—individual pieces reheated four to five times.

FORGING TEMPERATURE: 2250° to 2400° F.

FINISHING OPERATION: Wire brushing or sand blast—no machining.

On such a job it is obvious that oxidation and decarburization could not be tolerated under the dimensional tolerance demands.

The only possible way of handling this job was with "Atmosphere" heating. The stock to be forged was heated in a Surface Combustion Indirectly Heated Furnace supplied with NX (nitrogen), atmosphere produced in Surface Combustion Atmosphere Generators.

If you have any similar operations or if you contemplate any, by all means get in touch with a Surface Engineer.

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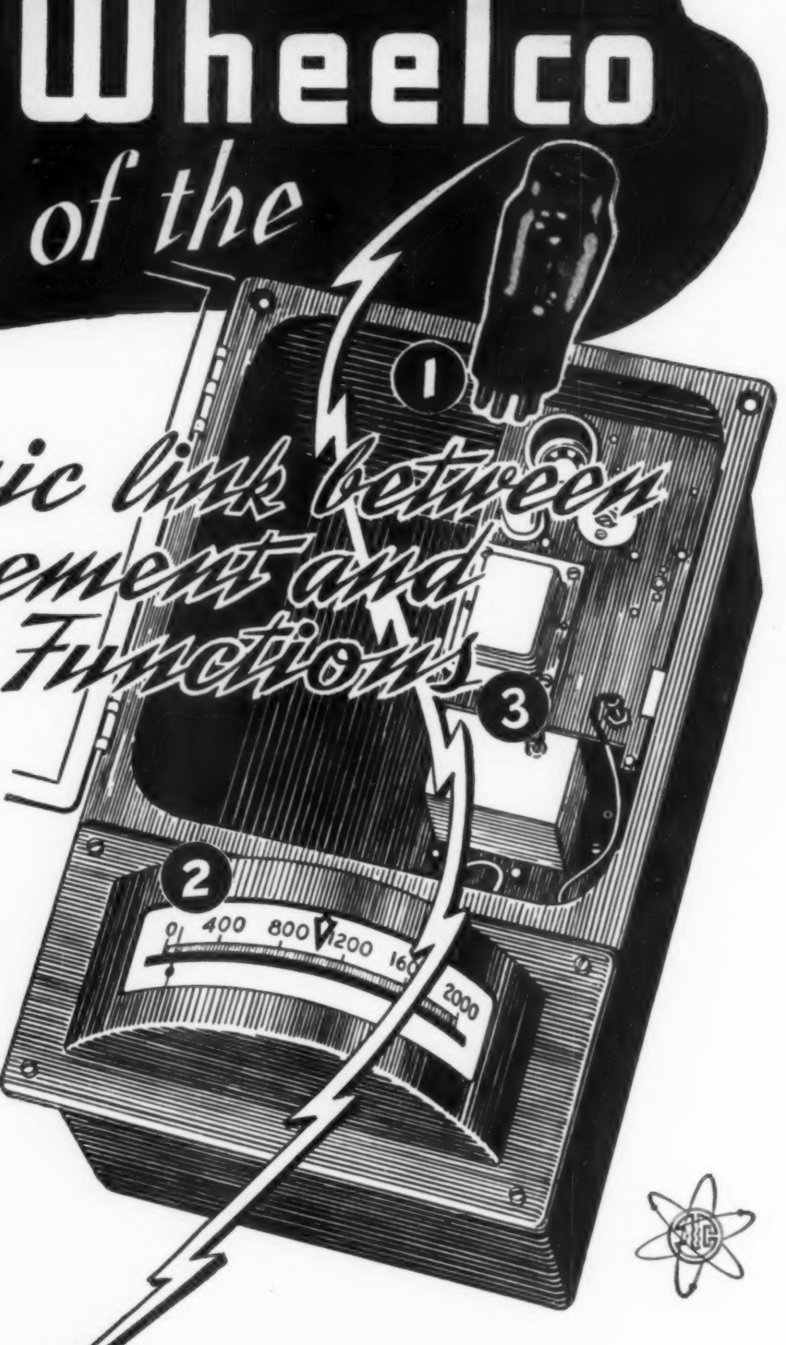

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DON COLWELL, *author of these reminiscences of his postwar investigations into the Japanese magnesium industry, is known for his connections with the American die casting industry. He is past-chairman of the Chicago Chapter, ⊕, and during the war he served in various activities concerning nonferrous metal supply, specification and use with the War Production Board and the Navy Department. His complete report on the Japanese nonferrous industry is contained in the report of the United States Strategic Bombing Survey, Pacific Theater.*

NOTES ON THE JAPANESE MAGNESIUM INDUSTRY

By DONALD L. COLWELL

District Manager, National Smelting Co., Chicago

METALLIC magnesium is comparatively new to industry so it is natural that activities should be expanding. The tremendous prewar growth of this industry in Japan, however, could be due to only one thing — a desire to make war. For example, the first Japanese outfit to produce magnesium was the Riken Metal Mfg. Co., founded in 1933 at Ube. Expansion was continuous; the Asahi Co. started production in 1937, three more organizations in 1939, and by 1941 six plants in Japan proper were producing magnesium; one had been started in Korea and one in Formosa. At the end of the war in 1945 six more organizations were producing magnesium, of which five plants were in Korea and one in Manchukuo. The location and production of each of these from 1935 to the end of the war is shown in Table I, page 68.

There are several basic processes for metal production. The Ube plant of the Riken Metal Mfg. Co. was based on brine; the raw material was a natural or "bitter" brine. A typical analysis is $MgCl_2$ 17.62%, $MgSO_4$ 6.48, KCl 2.88 and NaCl 3.55%. The brine was concentrated by evaporation and milk of lime added to precipitate $CaSO_4$ which was recovered and marketed as gypsum. The purified chlorides were then dehydrated in coal-fired pans, cooled, KCl and NaCl added. The mixture was crushed and completely dehydrated in electric furnaces with the evolution of chlorine and hydrochloric acid, which were recovered by absorption in milk of lime. The dehydrated chloride mixture was then electrolyzed. The metallic magnesium was cast into pigs under a sulphur dioxide atmosphere derived from burning sulphur. Difficulties were experienced with the short life of the dehydration pans and dehydrating furnaces, and from high power consumption.

This same general process was also used by the Japan Magnesium Co., and the Shinetsu Chemical Industries Co., in Japan proper, and by three plants in Korea, the Korea Light Metal Mfg. Co., the Korea Shinko Metal Mfg. Co., and the Mitsubishi Magnesium Co.

A second process, similar to that developed in Germany by the I.G. Farbenindustrie A.G., was installed by the Asahi Electrical Industries Co. at Ogu in Tokyo, and started operating in 1937. Magnesia and charcoal were crushed, mixed and fused in an electric furnace. Chlorine gas was blown through, and the anhydrous magnesium chloride thus formed was electrolyzed, forming metallic magnesium and chlorine, the latter being recirculated. This same general process was used by the Kanto Electrical Industries Co. and the Teikoku Magnesium Co. in Japan proper, by the Asahi plant at Takoa in Formosa, by the Manshu

Table I — Annual Magnesium Production,* Japan Proper, Korea, and Formosa
(In metric tons; add 10% for figure representing short tons)

Company	Plant	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
Japan Proper												
Asahi Elec. Industr. Co.	Ogu	—	—	62	264	421	336	239	225	236	233	2
Japan Magnesium Co.	Toyama	—	—	—	—	—	—	23	23	115	254	63
Kanto Elec. Indust. Co.	Shibukawa	—	—	—	—	258	820	826	892	962	702	131
Riken Metal Mfg. Co.	Ube	379	637	830	850	889	1125	808	674	1030	693	83
Shinetsu Chem. Indust. Co.	Naoetsu	—	—	—	—	249	219	247	213	319	328	84
Teikoku Magnesium Co.	Sakata	—	—	—	—	8	26	50	94	183	367	41
Sub-total		*379*	*637*	*892*	*1114*	*1825*	*2526*	*2193*	*2121*	*2845*	*2577*	*404*
Korea												
Asahi Light Metal Mfg. Co.	Kiyo	—	—	—	—	—	—	—	—	—	5	22
Korea Light Metal Mfg. Co.	Chinnampo	—	—	—	—	—	—	—	—	9	161	19
Korea Shinko Metal Mfg. Co.	Shingishu	—	—	—	—	—	—	—	20	200	446	128
Mitsubishi Magnesium Co.	Chinnampo	—	—	—	—	—	—	—	—	222	695	203
Mitsui Yushi Chem. Indust. Co.	Sanchoku	—	—	—	—	—	—	—	—	—	52	15
Nicchitsu Magnesium Co.	Konan	—	—	—	42	111	280	224	240	271	477	108
Sub-total		—	—	—	*42*	*111*	*280*	*224*	*260*	*702*	*1836*	*495*
Manchukuo												
Manshu Magnesium Co.	Eiko	—	—	—	—	—	—	—	—	—	402	92
Formosa												
Asahi Elec. Indust. Co.	Takao	—	—	—	—	—	—	142	297	381	310	—
Grand total		379	637	892	1156	1936	2806	2559	2678	3928	5125	991

*Figures for Japanese fiscal year, beginning on April 1 and ending March 31 of the next year.

plant in Manchukuo, and by the Korea plants of Asahi and the Mitsui Yushi Chemical Industries, also in Korea.

A third process was the carbothermic or Hansgirg process, begun in 1938 by the Nicchitsu Magnesium Co. at Konan, in Korea. This involved the high temperature reduction of magnesia by carbon with rapid condensation of magnesium powder in a stream of gas. This powder was subsequently recrystallized and then melted and poured into ingot. This process was used by the Permanente magnesium plant in California and — as is well known to American experts — many difficulties were experienced. The Nicchitsu plant seemed to be reasonably successful, producing about 3000 lb. of metal per day at peak operation (1944), but was the only plant to use this process.

•

Table II — Typical Analyses of Japanese Magnesium, 1945

Element	Riken Metal Mfg. Co.	Teikoku Magnesium Co.
Silicon	0.092%	0.025%
Aluminum	0.212	0.016
Iron	0.112	0.039
Copper	0.003	—
Zinc	0.030	—
Manganese	0.001	0.024
Magnesium (by difference)	99.550	99.896

A fourth process, the ferrosilicon or Pidgeon process installed in several American plants, was not used by the Japanese. Neither was sea water used in the brine process, although during the war further consideration was given to this source.

The principal magnesium bearing raw materials were two, magnesite and "bitter" brine. Dolomite (natural magnesium-calcium carbonate) was quarried and imported to the extent of several hundred thousand tons annually, but was not used as a source of metallic magnesium. Both the Light Metals Control Association and the Japanese Bureau of Mines were definite in their statements that lack of these raw materials was the cause of decreased magnesium production in Japan proper in 1944. Both of these agencies and officials of the Riken Metal Mfg. Co. also stressed the shortage of common salt as the most important factor contributing to loss of production of magnesium.

Because of these shortages in brine and salt, experimenting was begun in the use of sea water as a source of both magnesium and chlorine in 1941 by the Riken Metal Mfg. Co., on what they called the "magnesium hydrate" method.

The first production from this process was reported in July 1942, and by the end of the fiscal year 1944 production from sea water represented about one-quarter of Riken's production. In 1945 Riken was down to an inconsiderable 83 metric tons altogether, but of this 24 tons were from sea water. If the brine process plants had been

Table III — Examples of Japanese Magnesium Alloy Specifications

SPECIFICATION	ABBREVIATION	CHEMICAL REQUIREMENTS				MINIMUM PHYSICAL REQUIREMENTS	
		ALUMINUM	MANGANESE	ZINC	IMPURITIES *(a)*	TENSILE STRENGTH *(c)*	ELONGATION *(c)*
Wrought Alloys							
7311	Ri 201	5.0 to 7.0%	0.1 to 0.5%	1.5% max.	1.0% max.	31,000 to 37,000 psi.	3 to 10%
7311	Ri 202	8.0 to 11.0	0.1 to 0.5	1.0 max.	1.0 max.	37,000 to 42,500	5 to 7
7311	Ri 203	0.5 max.	0.5 to 2.5	0.5 max.	0.5 max.	25,500 to 30,000	2
Sand Cast Alloys *(b)*							
7317	Ri 501 *(a)*	3.5 to 6.5	0.1 to 0.5	2.5 to 3.5%	1.0 max.	25,500	5
7317	Ri 502 A	8.0 to 11.0	0.1 to 0.5	—	1.0 max.	21,300	1
7317	Ri 502 B *(d)*	8.0 to 11.0	0.1 to 0.5	—	1.5 max.	28,500 to 30,000	3 to 1
Die Cast Alloys							
7318	Ri 601	8.0 to 11.0	0.1 to 1.0	0.2 to 1.0	1.5 max.	—	—

(a) Impurity limits not given in Technical Institute specification book, but have been added in list of specifications prepared and published by Furukawa Electric Co.

(b) Note is appended to specification as follows: "Magnesium alloy sand cast test pieces have tensile strength of about 70% of tensile strength of forged test pieces."

(c) Minimum tensile strength and elongation required by the Japanese specifications vary with the thickness of the metal, in three groups: Under 1½ in., 1½ to 4 in. and over 4 in.

(d) Ri 501 annealed at 200 to 250° C. and air cooled. Ri 502 B heat treated at about 400° C. about 16 hr. and air cooled or may be tempered at about 200° C. for 16 hr. and air cooled.

designed to use sea water instead of brine, the magnesium production of Japan proper would not have suffered as much as it did toward the end.

A summary of the war period, 1941 to 1945, shows a production that doubled due largely to new plants in Korea and Manchukuo, and a sharp drop in 1945 due to lack of supplies and the shutdown in Formosa.

The distribution of the available metal was fairly simple, as about 90% of it went to aircraft in 1942, 1943, 1944, and 1945. This allocation included not only metallic alloys for airplanes themselves, but for airborne equipment, and magnesium for alloying with aluminum. The latter requirement probably amounted to almost 1500 metric tons per year during the war, as both 24S and the zinc-bearing aluminum alloys used by the Japanese contain about 1.5% magnesium. Practically the only "general uses" allowed during the war were the comparatively small quantities required for photographic flash bulbs, vacuum tube getters, and organic syntheses.

Electrical Equipment of the Riken Plant at Ube, Protected by Revetment. This plant was not damaged by air attacks. Plant executives were photographed with five Americans, Yeoman Wones, Donald Colwell, Lieut. Carl Beyer, U.S.N.R., Yeoman Huff, and Lieut. Arthur Freedman, A.U.S.

Comparatively small quantities of metal were used for pyrotechnics and for special indirect military purposes. If more magnesium had been available, it could have been used in place of aluminum in many aircraft parts, so the over-all position of magnesium is part of the aluminum situation. There was enough magnesium for alloying and pyrotechnics and uses where it was not interchangeable with aluminum.

American magnesium metal, as usually supplied, is better than 99.9% pure, although specification B92-39 of the American Society for Testing Materials requires only 99.8% minimum magnesium content. Analyses submitted by two of the leading Japanese producers, the Riken Metal Mfg. Co. and the Teikoku Magnesium Co., showed a lower purity. (See Table II.) Riken, in particular, using the brine process, had more trouble maintaining purity in 1944 and 1945 when the raw materials were short.

Specifications for Japanese magnesium alloys show the same lack of appreciation for quality that is apparent in their acceptance of impure magnesium. Typical examples translated from the Technical Institute's "Japanese Aeronautical Specifications, November 1944" give only nominal composition ranges. Similar specifications published by the Furukawa Electric Co. contain a limit for total impurities, usually 1.0%, sometimes 0.5% or 1.5%, as shown in Table III. No mention is made of the specific impurities, copper, nickel, and iron, which are harmful to corrosion resistance and are usually limited by American specifications to 0.03 or 0.05% each. In the "X" grade of the American Society for Testing Materials specifications B107-44T, B91-44T, and B90-44T covering wrought magnesium products, and B80-44T and B94-44T covering magnesium castings, nickel and iron are limited to 0.002, 0.004 or 0.005% to improve corrosion resistance. Such quality would be virtually impossible with the usual grade of Japanese magnesium ingot.

With the use of magnesium so definitely limited by the supply, the quality was probably good enough. It was certainly high enough to use as an alloying agent in aluminum alloys, and for pyrotechnic use. For aircraft landing wheels and other castings in engines and instruments it was also good enough. If supplies had been adequate to extend its use as a substitute for aluminum, higher quality would certainly have been necessary.

It is apparent that Japan was not ready, technically or economically, to exploit the use of magnesium to its fullest extent. The supply was short, even before the air raids on Japan proper, and it could be used therefore only where it was absolutely essential. The increases in production early in the war with us could not be continued because of lack of brine, magnesia and salt, all of which were imported from the continent. The blockade by our submarines caused this deficiency.

Air raids damaged magnesium production but slightly. Typical is a comment made by the Teikoku Magnesium Co., of Sagata, concerning two air raids, just before the end of the war — the only raids made upon this plant. The exact quotation: "On the 30th of June 1945, five mechanical mines were thrown on the plant as marked (A) on the map. They were thrown on the sand of the open, no explosion and no damage. On the 10th of August 1945, two bombs were thrown, one between the magnesium shops, and the other on the open as marked (o) on the map. By this attack 40% of these buildings in dia. 200m., mainly at the sidewall, suffered damages. The equipments were not broken. On the same times the sweeps of machine guns also were acted, but no damage."

Destruction in Osaka Was Typical of That in Tokyo, Yokohama, Kobe and Other Industrial Centers. Modern buildings, concrete chimneys and many telegraph poles withstood the fire, even though many of the buildings were gutted

The title of this article is written from the angle of news. It is news when electric furnaces are adopted for the production of tonnage grades of steel. It is an old story that electric furnace melters meet to discuss quality control; but the aim of these conferences is "high quality steel, consistently produced, day after day, in large quantities in a large number of plants".

ELECTRIC FURNACE PRACTICES FOR MELTING OPENHEARTH GRADES OF CARBON STEEL

Reported by CHARLES W. BRIGGS
Chairman of the Electric Furnace Steel Committee, A.I.M.E.
Technical and Research Director, Steel Founders' Society of America

AN ATTRACTIVE new feature of the fourth conference on electric steel, held in Pittsburgh early in December by the American Institute of Mining and Metallurgical Engineers, was the educational program, arranged for melters and their helpers, on the fundamentals of the chemistry of steelmaking. A lecture on the chemistry of the basic electric furnace process was presented by Gilbert Soler of Atlas Steels, Ltd. (Ontario), and C. E. Sims of Battelle Memorial Institute gave an illustrated talk on the chemistry of acid practice.

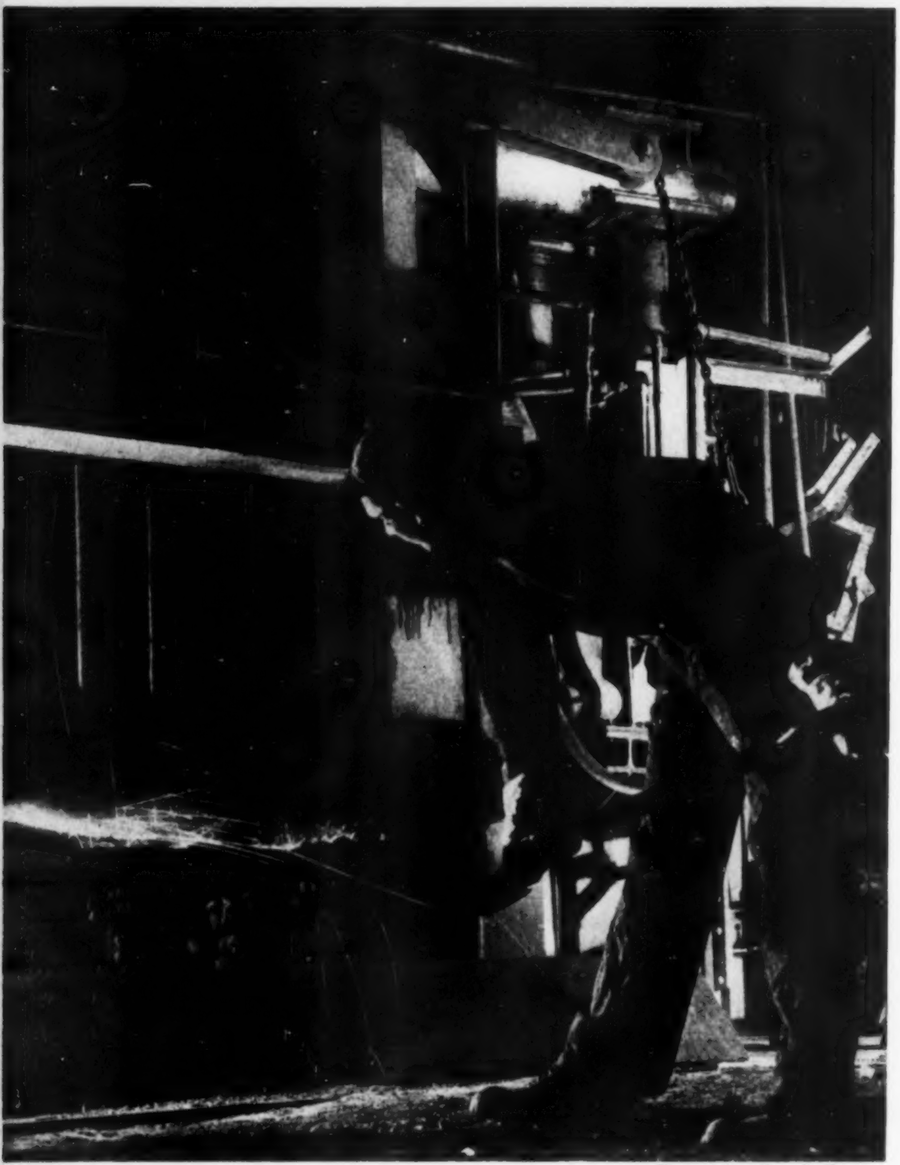
Following these lectures, attended by approximately 300 men, a panel of experts answered questions proposed by the operating men on all phases of production. This panel consisted of the following group:

Furnaces — Samuel Arnold, American Bridge Co.
Refractories — R. E. Birch, Harbison-Walker Refractories Co.
Acid Practice — C. E. Sims, Battelle Memorial Institute
J. B. Caine, Sawbrook Steel Castings Co.
Charles W. Briggs, Steel Founders' Society of America
Basic Practice — Gilbert Soler, Atlas Steels, Ltd.
Harold E. Phelps, Rotary Electric Steel Co.
Harry W. McQuaid, Consulting Metallurgist
William J. Reagan, Pennsylvania State College

The usual number of technical papers (and free discussion) occupied the other two days of the conference. Some of the important points brought out at the various sessions will now be recorded.

Electric Furnace Electrodes — There are a number of advantages favoring the use of an electrode of large diameter for furnace operation. These are *(a)* a lower electrical resistance which increases production because it increases power input, *(b)* a better distribution of heat over the hearth and greater uniformity of temperature within the furnace, *(c)* a retarded rate of boring down initially through the cold charge, with the result that an adequate pool of metal is formed, *(d)* the large electrodes are more resistant to mechanical stresses, *(e)* joints must be assembled less frequently, which saves a certain amount of time and labor, *(f)* the greater cross-sectional area causes a lower percentage of power loss resulting from electrode resistance.

These points were made by T. L. Nelson of the National Carbon Co. during his discussion of carbon and graphite electrodes for electric furnaces. It was also indicated that test results showed the superiority of the new graphite nipple over the old carbon nipple, both in strength (50% greater) and electrical properties (185% better conductiv-



An Addition

Republic Steel Corp.

ity). An Acme-threaded graphite nipple of similar diameter to the round-thread carbon nipple and but three-fourths the length made the best joint for strength and electrical resistance. Recommended dimensions for the Acme-threaded nipple are: Pitch diameter about 0.5 times the electrode diameter and length 1.5 times the nipple diameter.

Scrap Distribution — The preparation of raw materials for fast melting in an electric arc furnace was the subject discussed by S. D. Gladding of Bethlehem Steel Co. Mr. Gladding showed six color slides of the inside of an electric furnace which vividly illustrated his points concerning proper and improper charging techniques.

Preparation of scrap is of paramount importance today because so much of the scrap now available is unfit for direct melting. The objectives are to make the scrap chargeable by proper sizing, to produce a more compact charge, and to remove foreign material. The most commonly used methods of preparation of scrap are to shear or torch-cut bulky or long scrap. Heavy castings, forgings and risers are often blasted with dynamite. Stringy turnings are crushed in hammer mills and then briquetted. Light scrap, such as wire and tinplate, is bundled. Skulls and heavy fragile materials are broken with a large steel ball, handled with a magnet hoist.

Basic Electric Oxidizing Period — The oxidizing period in electric steelmaking begins with the first drop of metal melted and ends with the first addition of a reducing agent to the bath or slag. As pointed out by Alex C. Texter, Atlas Steels, Ltd., the oxidizing practice has an all-important influence on the development of the heat and on the quality of the finished metal. There are three distinct methods of oxidation and the selection depends upon the character of the scrap, the grade of steel to be melted and the quality desired:

1. Limited oxidation during melting followed by a vigorous boiling period. This method produces steel of low inclusion and gas content.
2. Addition of ore with the charge to produce oxidation during melting; there is no definite boiling period. This method is more economical but the quality of steel will not be as high.
3. As little oxidation as possible and without boiling. This method is suitable for the making of machinery grades and high alloy steel from select scrap requiring high alloy recovery.

The basicity of the oxidizing slag is important for the effective removal of phosphorus. A lime-silica ratio of at least 2.5 to 1 is necessary. In practice, to obtain a phosphorus content in the steel lower than 0.03% when using high phosphorus scrap, it is necessary to add limestone equal to 6 or 7% of the weight of the charge. Further additions of lime are necessary after meltdown.

A good boil for the production of high quality steel is accomplished in a period of 45 to 60 min. with a drop of 20 to 25 points of carbon. This means that, if the carbon is to be boiled down to say 5 points below the finishing range, a melt-in carbon should be approximately 20 points above the low side of the specification. For example, a steel specified to have 0.30 to 0.35% carbon should melt down at 0.45 to 0.50% carbon and 0.50 to 0.60% manganese.

The bath is often partially deoxidized before the oxidizing slag is removed, by reboiling with ferromanganese or spiegel additions, or by immersing the electrodes in the bath. Reboils are advocated for lowering the FeO content of the steel, and eliminating silicate inclusions by the formation of fluid manganese silicates. These reboils must be timed properly so they are far enough ahead of the slag-off to remove the maximum amount of silicates, yet not too far in advance of the slag-off so that the action will tend to reverse and reoxidize the bath.

Rimmed Basic Steel and Semikilled Electric Steel — Electric furnace steel has always been considered as a high cost steel; hence, the production of openhearth grades in the electric furnace has aroused much interest. A. K. Moore, Steel Co. of Canada, Ltd., stated that when scrap undersells pig iron, the lower cost of raw material plus cheaper furnace repairs, together with higher yields, offsets the higher costs for electric heat and labor.

All grades of rimming steels which are produced in the openhearth can be made in the electric arc furnace. These grades range from under 0.07% carbon deep drawing grades up to 0.28% carbon commercial and cold heading grades. Satisfactory rimming action for steels under 0.10% carbon can be obtained with the FeO content of the slag ranging from 13% upward. For higher carbon steels a slag containing 11% FeO and upward will produce satisfactory rimming at proper temperatures.

The relatively slight oxidizing atmosphere of the electric arc furnace as contrasted to that obtained in the openhearth requires approximately 30 lb. of iron ore per ton for 0.10% carbon drop, as compared with only 4 lb. for the same action in the openhearth.

Production of semikilled steel of the 0.08 to 0.20% carbon grades in the electric furnace to compete with similar openhearth grades depends upon low initial power costs and very fast charging and melting operations (high tonnage per hour). These principles and many other facts regarding the production of semikilled steel were presented by Ray J. McCurdy of Republic Steel

Ready to Tap

Bethlehem Steel Co.

Corp., who has perfected a practice of fast charging and melting, tapping without blocking, all additions in the ladle, and pouring in open molds. The first carbon test is planned to be about 5 points above the desired range. Ore is added, together with sufficient lime to produce a lime-silica ratio of 1.8 to 1. The FeO content of the slag will vary from 14 to 19% for steel containing 0.18 to 0.11% carbon.

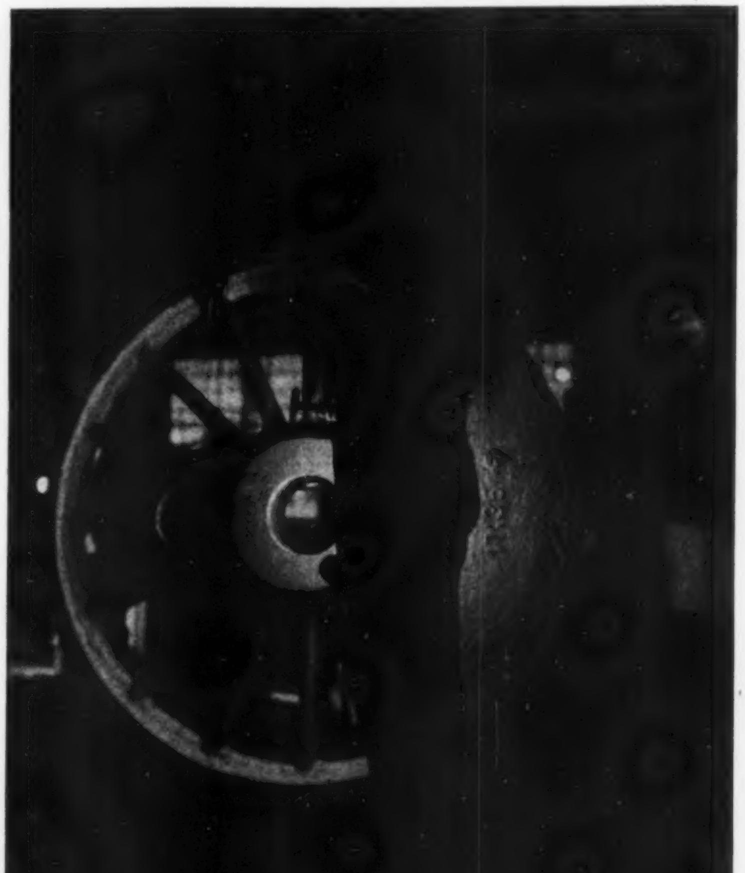
The slag is flushed off freely during melting. This operation removes phosphorus from the heat. Phosphorus and sulphur requirements of 0.04 and 0.05% max. respectively are not difficult to meet. Phosphorus reversion is very infrequent and, since no block is used, phosphorus is reverted to the metal only when the metal separates poorly from the slag in tapping. Sulphur drops about 0.008% during the heat to produce an average ladle test of 0.036%. If there is a higher sulphur melt-in — for example, up to about 0.065% — sulphur can be brought down without much delay by increasing the slag basicity to about 2.2 to 1. Slag flushing saves much time in making this adjustment.

Argon Gas Used in Steel Melting was described by William M. Farnsworth of Republic Steel Corp. It controls the bleeding of ingots sometimes experienced in heats of stainless steels. The gas is introduced through a carbon steel pipe inserted into the bath through an open door, with its end held close to the bottom of the bath. Argon is piped through a main line with an outlet to each furnace where a 50-lb. gage is located. A high pressure rubber hose connects the fixed outlet to the blowpipe; the diameter of the latter depends on the furnace size. Argon is bubbled through the bath until periodic sampling indicates that bleeding is not to be feared. Bleeding is considered to be due to more than normal hydrogen in molten steel; the argon probably removes the hydrogen through the flushing and stirring action of the bubbles of inert gas. The best period for the argon treatment is just prior to tapping.

Acid Electric Slags — One of the most useful of the tools developed for acid melting practice, according to George R. Fitterer of University of Pittsburgh, is the slag-fluidity test. Slag fluidity may be used to indicate the trends in acid electric heats provided the readings are taken before or a sufficiently long time after ore additions. Slag fluidity indicates *(a)* slag analysis, particularly when the charge is uniform with respect to manganese, *(b)* metal temperature and temperature changes, *(c)* the rate of carbon drop and *(d)* the general finishing conditions of the heat. Heats tapered off to the same slag fluidity will taper off in carbon content as well as in temperature; heats changing rapidly in fluidity at the finishing stages are also changing rapidly with respect to carbon content and temperature. Slag fluidity determinations were all made with the ⅜-in. bore mold. Correlation between acid openhearth slags and acid electric slags is very good.

The use of the "silica degree determination" was suggested by E. C. Troy of Dodge Steel Co. for defining an acid slag and the type of acid and basic slags. He said that, since acid slags tend to approach saturation with respect to SiO_2 at all times, there was very little that the melter could do to control them in the time available in the normal melting practice. Also it appears that these slags have little influence on the metal quality. Mr. Troy suggested the use of tuyeres in the electric furnace and the addition of a gas such as oxygen or nitrogen to create an artificial boil,

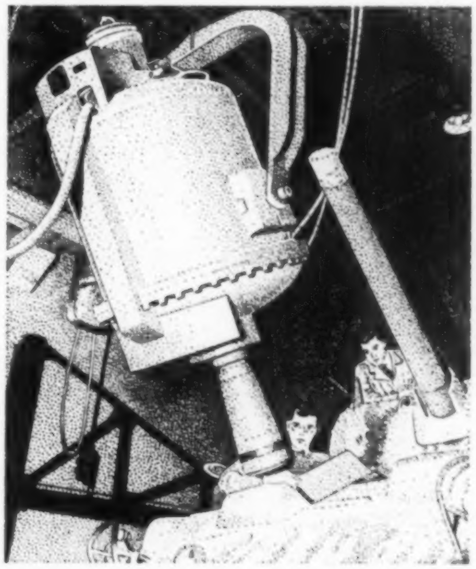
Rings True



Birdsboro Steel Foundry & Machine Co.

thereby reducing the carbon content and eliminating inclusions without resorting to oxidizing slags.

A contrary point of view was taken by J. B. Caine of Sawbrook Steel Castings Co., who pointed out that, through control of the iron oxide of the slag by slagging operations, the iron oxide content of the slag could be lowered independently of the carbon content, thus reducing the amount available for reaction with the metal bath. Slags low in iron oxide were advocated for producing coarse-grained cast steels. Also, the low FeO content of the metal would reduce the inclusions by increasing the fluidity of the steel.



Sulphur (and what can be done about it in acid electric practice) — There is no elimination of sulphur in the normal acid process, yet sulphur has long held the reputation of being harmful to steel castings. Because of this situation, a session was held concerning the effects of sulphur and what can be done, if anything, about it. G. A. Lillieqvist of American Steel Foundries described at length the more important effects of sulphur: When a critical amount of aluminum is added to finished steel, the harmful stringer-type inclusions are formed; with low sulphur content, below 0.025%, the ductility properties are not seriously affected by these inclusions but in the higher sulphur ranges a tremendous drop in ductility occurs. Increasing the sulphur contents lowers the notched-bar impact properties. Sulphur decreases the strength and ductility of steel in the region of 2400° F.; thus, increasing sulphur contents makes a cast steel more susceptible to hot tears.

Aside from the basic electric melting process, the only practiced method of sulphur control now known is the careful selection of scrap steel. There are several proposed methods for removing or neutralizing sulphur in the acid electric process. One of these methods, the Perrin Process, was described by Jerome Strauss, of Vanadium Corp. of America, wherein the steel is made by the acid process and then tapped from a height of about 10 ft. into a molten slag of fairly high alumina content. Intermixing of steel and slag reduces the sulphur content, from say 0.06% in the bath to 0.02% in the ingot. There are no installations of this process in this country.

The alkali treatment of cupola metal, as used in the triplex method, was discussed by H. C. Be Ment of Campbell, Wyant and Cannon. This process is very effective in removing sulphur in the raw materials but it is difficult to reduce it to levels below 0.04 or 0.05%. Likewise, the method cannot be used on finished steel.

There is also a possibility that the use of spodumene will reduce the sulphur content. G. T. Motock of Metalloy Corp. stated that the use of lithium is indicated, since its reaction with sulphur forms a gas which would leave the metal. Further studies are necessary before quantitative trends can be established. C. N. Arnold of Union Steel Casting Co. related his experiments with sodium as a deoxidizer; figures were given which indicated that sulphur could be reduced from 0.028 to 0.020%.

Studies on cast steels were reported by T. N. Armstrong, International Nickel Co., to show that by the addition of calcium-manganese-silicon and selenium to the ladle a selenium sulphite type of inclusion was formed which was not harmful to the ductility of cast steel even in the presence of aluminum and high sulphur contents.

Metallurgy of Quality Steel

Aside from the more-or-less practical aspects of steelmaking, thus noted briefly, a session held jointly by the acid and the basic steel metallurgists considered the physical chemistry of the two processes. The published proceedings of the conference will contain the complete texts. Its quality may be judged by the roster of speakers: C. E. Sims, Gerhard Derge, S. F. Urban, Axel Hultgren, G. R. Fitterer.

As a matter of fact, steel quality rather than tonnage production was the primary concern of the entire conference, and probably will be the aim of many conferences to come. High quality steel is nothing new. Yet high quality steel consistently produced, day after day, in large quantities by a large number of companies is a goal that has not been obtained. Nevertheless it is being studiously sought. The paths by which we arrive at this destination will be quality control through process control and by complete dissemination of information. ●

BIOGRAPHICAL NOTES OF EMINENT LIVING METALLURGISTS

Alfred Lindley Boegehold

PRESIDENT, AMERICAN SOCIETY FOR METALS

ON THE SURFACE OF THINGS there would seem to be little connection between some of Shakespeare's philosophy and the Research Laboratories of General Motors Corp. in Detroit. The two seem too wide apart in space, time, and intent; yet Alfred Lindley Boegehold, metallurgical chief in this research organization, is proof that, as Hamlet said, "There's a divinity that shapes our ends, rough-hew them how we will."

Young Boegehold, fresh from college, went far astray from the direct route that finally led him to his goal. The truth of the matter is that he didn't seem to have a goal, holding jobs anywhere from a few days to a few months. Worse than that, he took jobs that he certainly must have known he couldn't hold. But all through these shifting young years a great underlying truth of living was being worked out, just as it has been worked out countless times before. There *is* a divinity that shapes our ends, rough-hew them how we will! Those "shiftless" years were actually not shiftless — they were only the years when a young man was trying to find himself.

Alfred Lindley Boegehold was born in Mount Vernon, N. Y., on Oct. 31, 1893. He graduated from Cornell in 1915 with a degree in mechanical engineering. While in college he was not heavy enough to make the varsity crew, but he did make the Junior Varsity that won its race in the Poughkeepsie regatta in 1914.

His first post-college job was with Remington Arms at Bridgeport, Conn., then making ammunition for the British, Russians and French in World War I. He started as a machine operator and later was transferred into time-study and efficiency engineering projects. One of his buddies on this job told him of the great opportunities that came to men who worked in the openhearth departments of steel mills, so young Boegehold went to Bethlehem and was hired as third helper. After four days he thought differently of the opportunities!

Returning home to Mt. Vernon, he saw a newspaper advertisement for a toolmaker at the Fiat Automobile Co. in Poughkeepsie. He answered the ad, got the job and in two hours flat proved to the entire satisfaction of the foreman that he definitely was not a toolmaker. He was then given a job on a lathe where he worked for six weeks to the satisfaction of all concerned, until again the urge to move on asserted itself. Bridgeport Brass was his next employer, where for about six months he was foreman in the ingot casting department. There the first Ajax-Wyatt low frequency induction furnaces were being introduced for the melting of brass prior to casting into extrusion billets.

On the next change he really "hit the jackpot" — although those were not the words used at the time: He returned to the Remington Arms plant — now making Browning machine guns and Colt 45's — and entered the testing department, and was lucky enough to work under Harry M. Williams (now vice-president of National Cash Register in Dayton). Metallography caught his fancy. It intrigued him. He began to educate himself in this specialty, and this education, starting in 1917 and broadening into general metallurgy, has continued "right up to now", as he says.

The ending of the war ended this job. Boegehold with others then went to Washington where he worked under the late Dr. George K. Burgess at the Bureau of Standards, finishing up some studies on machine gun barrels. Six months later, having processed 25 different steels from crucible heats on through to installation in test guns, he went back to Bridgeport as metallurgist for Remington U. M. C., where the manufacture of cutlery had been started after the war. About a year later his old chief, Harry Williams, asked him to come to Dayton and join the newly organized General Motors Research Laboratory. In October 1920 Boegehold accepted. Twenty-seven years later he still works for G. M.

When the Research Laboratory moved from Dayton to Detroit in 1925, Harry Williams stayed behind in Dayton, and Boegehold moved up, as head of the metallurgy department, which position he has held ever since. The influence of his work on General Motors production has grown steadily and solidly. The Laboratories, being an autonomous unit, work on problems common to the entire industry and render consultation and laboratory services to the other divisions of the parent corporation.

While still in Dayton, Boegehold worked out the first oilless porous bushings made of powdered metals, now known as Durex. Since then he has done much to perfect the art of powder metallurgy, both as to the production of the metal powders and their further manufacture into machine parts. Consequently he holds several patents on powder metallurgy, both ferrous and nonferrous. Included among these are processes for making iron powder and steel powder, and also for heavy duty bearings made with copper and nickel powders bonded to a steel back — a porous matrix impregnated with lead babbitt (now known as Durex 100). Also developed were steel-backed, copper-lead bearings.

For this work on bearings, he was named by The National Association of Manufacturers in a joint award with Harry Williams and Norman Gillman as a "National Modern Pioneer".

One of Boegehold's principal lines of activity — dating back to the early days in Dayton when they were making cast iron cylinders for the "copper cooled engine" — has been the application of metallurgical science to the foundry. This naturally led to interest in raw materials and their effect on the product — the subject of the first paper he presented to a technical society. (This was before the A.F.A. in 1929; for it he was awarded the J. H. Whiting prize.) Several papers followed on cast iron and malleable iron, dealing with annealing and melting. As a result of these contributions and service on various committees, the A.F.A. awarded him the J. H. Whiting Gold Medal in 1942.

Another less formal award has greatly pleased Boegehold. It was awarded in 1938 and is the Ph.D. of the Cafeteria Institute of Technology "For Achievement in Gaseous Pearlitic Malleable"! The C.I.T. is composed of a group of metallurgists in the Detroit area who eat together in the cafeteria across the street from the big laboratory building, which luncheon meetings generally resolve into metallurgical discussions.

Boegehold, in common with other metallurgists whose formal education was in other branches, has found that his technical education as a mechanical engineer is most useful to him as a metallurgist in the application of metals, since so many metallurgical problems turn out to be problems in design. In the field of melting, casting, and heat treating, of course, there is less connection between the two branches. But since the application of metals in industry is of such wide and vital scope, his early training has been most useful. It results that, under his direction, the metallurgy department of G. M. Research Laboratories functions in a number of ways:

1. Metallurgical research on problems common to more than one G. M. division.
2. Consultation and laboratory service to divisions.
3. Consultation and service to Research Laboratories departments. This includes prescription of materials and heat treatments on engines and devices being built by the Laboratories, doing the heat treating, making castings, and fabrication by copper brazing and silver soldering.

The greatest contributions of this department to the war effort came through developments that were made just before the war. The Jominy hardenability test was instrumental in determining the compositions of the National Emergency steels and saved innumerable hours in testing the hardenability of constructional steels and armor and shot steels. The introduction of pearlitic malleable iron for pistons in diesel engines (G.M.) and for camshafts in gasoline engines established an available source of such material that later led to great savings through replacements of forgings in guns and other armament items. Again, the use of pearlitic malleable in place of aluminum for diesel engine pistons was a large factor in obtaining durability and long life in these engines which were used extensively in submarines and in a variety of naval auxiliaries.

When armor plate manufacture was getting under way, the hardenability necessary for hardening throughout was determined for various thicknesses of plate. Adherence to these values by several armor manufacturers was responsible for an excellent ballistic performance record. One assignment handled by Boegehold and his staff was the modification of the metallurgy of the Allison crankshaft to permit an increase in horsepower from 1050 to over 1500. Another assignment was the development of cast armor piercing shot for 75-mm. guns, equal in performance to those made from rolled steel. This was accomplished and proved by direct comparison on face hardened armor, although such shot was not put into production by the war's end. Among consulting jobs with G. M. divisions was the establishment of correct procedure and equipment for manufacturing the Aero Products' hollow steel copper brazed airplane propeller.

Alfred Boegehold was married to Katherine E. Yager of New York City in 1925. They have five children, three boys and two girls.

For diversion Boegehold plays a bit of golf and bowls some. According to him his greatest achievement in the world of sport was made in New York City where in three games he bowled a total of 775 on a well-grooved alley and with round-bottom pins.

Alfred Lindley Boegehold ("Bergy" to his intimates) has long taken an interest in ⊕ affairs, both local and national. His home city associates elected him chairman of the Detroit Chapter in 1938; that same year he became member of the National Publication Committee. Elected national trustee in 1944 and vice-president in 1945, he graduated into the presidency at the 1946 election. He is equally well-known in the affairs of the American Foundrymen's Association, and takes an active part in the work of the Society of Automotive Engineers. His advice is sought and his opinion respected by his professional brethren.

Russell Raymond Voorhees

Three years of wartime production of a single vehicle, the world-famous Willys "Jeep" and its ¼-ton trailer, have afforded an unusual opportunity to make statistical surveys of the physical properties obtained by the heat treatment of steel parts. A review of this data has had three useful results: (a) Improved the methods of specifying physical properties; (b) revised the specification values for parts that continue in production on the peacetime model; and (c) gathered information on the intrinsic metallurgical properties of different steels, thus enabling the metallurgical department to select adequate materials at the lowest cost.

A STATISTICAL SURVEY OF SOME HARDENED STEEL FORGINGS

By ROGER F. MATHER*

Chief Metallurgist, Kaiser-Frazer Corp., Willow Run, Mich.

DURING recent years the standard tensile test has apparently lost a considerable amount of the prestige it has traditionally enjoyed in the evaluation of steel forgings. For one thing, studies of hardenability have emphasized that the tensile properties represent the combined results of an inherent property of the material (namely, its hardenability) and the processing (namely, the rolling, forging, and heat treatment). For another, service life has been shown to depend to a marked extent on the condition of the surface of the part, both as regards its contour and finish, and the presence of residual stresses.

Other disadvantages of the tensile test have long been recognized. Since the tensile strength can be accurately predicted from the Brinell hardness, the main purpose of the test is to determine the yield strength and ductility, and usually these can be correlated with service life only indirectly and approximately. Moreover, test specimens are commonly taken from the center of the piece, so that parts loaded in bending and torsion — which comprise the great majority — are tested only in the region of the neutral axis where stresses are inconsiderable.

Despite these shortcomings, the fact remains that tensile testing is firmly fixed in the minds of many engineers and metallurgists, and specifications for these properties will probably be continued for a long time. The present survey was made with the aim of determining the possible usefulness of some accumulated data, taking for granted their limitations along the lines mentioned above.

"Y" and "P" Factors — A typical specification for the tensile properties of a hardened and tempered part, for instance, one made from 1040 steel and tempered to 212 to 248 Brinell, might read as follows:

Tensile strength, min.	100,000 psi.
Yield strength, min.	65,000 psi.
Elongation in 2 in., min.	20%
Reduction of area, min.	50%

In this specification the values are established so that all pieces made from the proper material and properly heat treated will meet the requirements. The steel is generally accepted on the basis of

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*The work described in this paper was performed while the writer was chief metallurgist of Willys-Overland Motors, Inc., Toledo, Ohio, and the parts referred to are those of the Jeep and its ¼-ton trailer. The writer wishes to express his thanks to the company, and particularly to D. G. Roos, vice-president in charge of engineering, for permission to publish the results.

Table I — Parts Used in Statistical Survey of Physical Properties

Part Name	Grade of Steel	Quenching Medium	Cross Section	Final Brinell
Axle spindle	1040	Oil	1½ round	207 to 255
Lunette eye	1045	Oil	1¾ round	192 to 241
Crankshaft	1040	Water	1 7/16, 2 3/16 round	207 to 255
Connecting rod	1141	Oil	¾ square†	228 to 255
Steering arm and bell crank	*	Oil	¾ square†	277 to 321
Crankshaft bearing cap screw	*	Oil	7/16 round	302 to 364
Spring clips	*	Oil	7/16 round	321 to 351

*0.35 to 0.42% mean of carbon range in 1300, 4000, 8600, 8700 or 9400 series.

†Test bars forged from production steel and heat treated with parts.

chemical analysis alone, with the possible addition of hardenability requirements; the inability to produce certain physical properties after hardening and tempering is not usually cause for rejection. In the majority of instances the function of physical tests is therefore solely to check on the heat treatment.

Table II — Distribution of Tensile Strengths of Parts Made of Plain Carbon Steels

Tensile Strength	Axle Spindle	Crank-shaft	Lunette Eye	Connecting Rod
96,000		1	1	
98,000		3	2	1
100,000	3	10	2	17
102,000	5	22	1	34
104,000	13	29	1	28
106,000	14	16	9	20
108,000	20	33	7	30
110,000	14	17	11	17
112,000	11	13	6	17
114,000	11	7	7	16
116,000	11	13	2	5
118,000	9	5	3	3
120,000	8	3		—
122,000	2	2		—
124,000	—			—
126,000	—			1
128,000	1			
Total	122	174	52	189
low ¼	105	103	106	102
high ¼	116	112	114	112

Variations in physical properties result from variations in making and heat treating the steel. The effects of the steelmaking practice, including analysis and grain size, are influential through their effect on hardenability. In the heat treatment, two major factors which are subject to some fluctuation are the quenching and tempering temperatures. Specifications for physical properties are established so that all such factors may be simultaneously at their least favorable limit, while still within the bounds of acceptable practice.

In a properly heat treated piece of given design and material, fluctuations in yield strength parallel those in the tensile strength, so that a minimum ratio of yield to tensile can be maintained. However, in the type of specification quoted above the minimum values for yield and tensile strengths are of necessity so low that a piece improperly hardened and having therefore a high tensile strength as compared with the yield may still meet the requirements. Similarly, low tensile strength is matched by correspondingly higher ductility if the piece has been properly heat treated; yet here again in this type of specification a piece having both low strength and low ductility — the result of improper heat treatment — can still meet the requirements. The addition of maximum values, thus specifying the permissible range of the various properties (which represents another common practice in specification writing) does not overcome these disadvantages.

These shortcomings may be eliminated by using different criteria for the success of heat treating operations, namely the "Y" factor, defined as the yield strength divided by tensile strength multiplied by 100:

Table III — Distribution of "Y" Values of Parts Made of Plain Carbon Steels

"Y" Value	Axle Spindle	Crank-shaft	Lunette Eye	Connecting Rod
60%	1	2	2	
62	—	1	2	
64	2	6	7	
66	7	21	20	
68	19	66	22	
70	27	50	3	
72	22	25	1	14
74	6	2		28
76	3	1		47
78	2			37
80	1			28
82				12
84				13
86				4
88				5
90				—
92				1
Total	90	174	57	189
low ¼	67	66	64	74
high ¼	73	71	69	81

$$Y = \frac{Y.S.}{T.S.} \times 100$$

and the "P" factor, defined as the tensile strength in kips (psi. ÷ 1000) plus the reduction of area in % multiplied by 6, the sum then being divided by 5.

$$P = \frac{1}{5}\left(\frac{T.S.}{1000} + 6\ R.A.\right)$$

The maintenance of a minimum "Y" value assures that the yield strength is in line with the tensile, while a specified "P" factor may be regarded as a requirement for ductility in which allowance has been made for variations in tensile strength.*

These factors also have the property that, on tempering a piece of hardened steel at succesively higher temperatures, "Y" decreases only about 10% as the hardness decreases from 400 to 200 Brinell, while "P" remains substantially constant. Hence the tensile properties of different steels may be compared even when tempered to different hardness levels. For this reason a statistical survey of tensile properties is more profitable when based on the derived "Y" and "P" values, rather than on observed values.

Table V — Distribution of Charpy Impact Strengths of Parts Made of Plain Carbon Steels

Charpy Value	Crankshaft	Lunette Eye	Connecting Rod
20 ft-lb.	1		
22	1		
24	2	1	
26	3	5	
28	6	13	6
30	10	7	8
32	22	6	28
34	12	5	20
36	29	5	29
38	16	2	19
40	20	4	30
42	8	1	7
44	15	3	7
46	5		4
48	3		1
50	—		3
52	1		1
54			2
Total	154	52	165
low ¼	31	27	32
high ¼	42	37	41

Table IV — Distribution of "P" Values of Parts Made of Plain Carbon Steels

"P" Value	Axle Spindle	Crankshaft	Lunette Eye	Connecting Rod
74		1		
76		2		
78		3		3
80		—		1
82		4		—
84		8	1	5
86		6	3	5
88	5	18	7	5
90	19	15	8	22
92	21	33	17	37
94	21	42	8	36
96	12	31	10	48
98	7	7	3	24
100	5	4		2
102		—		
104		1		
Total	90	175	57	188
low ¼	90	88	89	90
high ¼	96	96	96	97

The parts used in this survey are listed in Table I, which shows the grade of steel, the quenching medium, the cross section of the part or test bar in the region where the properties were determined, and the Brinell hardness range specified after hardening and tempering. About four tests per heat of steel were made on all parts except the crankshaft, on which two per heat were made. Some of the parts were heat treated in the Company's own plant, in which event the test specimens were cut from the parts themselves wherever their shape permitted; otherwise the specimens were made from test bars forged from production steel and heat treated with the parts. The cross section of the test bars was made approximately equal to the critical section of the part, except that square test bars are preferred because they are more easily forged. Where the parts were heat treated in vendors' plants, namely the axle spindle and crankshaft bearing cap screw, all tests were made on specimens cut from the parts themselves. Tests on the crankshaft were made on a coupon cut from the front end, and the test bars fractured sometimes in the smaller and sometimes in the larger diameter of this coupon; this accounts for the scatter of results on the crankshaft being somewhat greater than in the other parts. All test specimens were cut parallel to the direction of grain flow.

Other bolts and studs tested for physical properties were too small to afford tensile test specimens, and their ductility was consequently tested by means of impact and bend tests. Hence the results on this group of parts could not be included in the present survey.

The distribution of physical properties is shown in Tables II to IX. For purposes of comparison the "probable" values have been calcu-

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*Charts enabling the testing engineer to read off the "Y" and "P" value directly, given the yield, tensile and reduction of area, were published in *Metal Progress* for March 1946, page 552-B. These diagrams reappear as No. 58 in the 1946 collection of "Metal Progress Data Sheets".

lated by discarding the top and bottom 25% of values. Yield strengths were measured as the load required to produce 0.2% offset in 2 in. In correlating hardness values with other physical properties, it should be borne in mind that the former refer to the *surface* of the parts, the latter to the *center* of the sections. Figure 1, page 84, shows the relationship between average "Y" and "P" factors, based on the numerical averages for each part and grade of steel.

In the plain carbon steel parts all properties are substantially equal — that is, the maximum on the frequency curves if drawn would be nearly at the same value, irrespective of the part from which

Table VI — Distribution of Tensile Strengths of Alloy Steel Parts*

TENSILE STRENGTH	PITMAN ARM AND BELL CRANK				CRANKSHAFT BEARING CAP SCREW					SPRING CLIPS		
	1300	4000	8700	9400	1300	4000	4100	8700	9400	1300	4000	9400
120,000		6	2	5								
124,000		8	2	8								
128,000	1	6	1	12								
132,000	—	6	3	19								
136,000	3	4	3	22								
140,000	4	—	2	13	1	1						
144,000	7	—	—	12	1	1						
148,000	3	—	—	6	—	—						
152,000	3	2	—	7	1	3	3	1	1	5	2	4
156,000		—	—	2	2	3	4	3	4	9	—	10
160,000		2	1		2	10	9	2	9	9	4	19
164,000					2	15	—	7	8	12	—	17
168,000					3	14	5	8	9	10	1	21
172,000					5	8	6	13	9	2	2	17
176,000					6	6	5	11	8	1	—	11
180,000					6	7	—	7	5	—	3	5
184,000					4	3	—	2	1	2		3
188,000					1	2	—			1		2
192,000					3		—			3		2
196,000					—		1			1		
200,000					1		2					
Total	21	34	14	106	38	73	35	54	54	55	12	111
low ¼	140	122	124	129	164	161	158	164	160	156	158	160
high ¼	148	135	138	143	184	176	171	177	176	169	180	174

*Carbon contents of steels of the various types shown in Tables VI to IX were 0.37 to 0.42%, mean of range.

Table VII — Distribution of "Y" Values of Alloy Steel Parts

"Y" VALUE	PITMAN ARM AND BELL CRANK				CRANKSHAFT BEARING CAP SCREW					SPRING CLIPS		
	1300	4000	8700	9400	1300	4000	4100	8700	9400	1300	4000	9400
72%		1										
74		2										
76		7										
78		10		1								
80		10	4	—								
82	2	—	4	5							1	
84	2	1	2	7						2	2	1
86	2	1	2	12						3	4	7
88	6	1	1	12		2				3	—	3
90	4	1	—	22	1	2			1	—	1	6
92	3		2	25	5	6	4	2	1	7	—	12
94	2			13	10	27	16	13	17	17	4	18
96				7	19	9	9	19	13	21	1	24
98				1	1	3	2	1	12	2		31
100					1							2
Total	21	34	15	105	37	49	31	35	44	55	13	104
low ¼	85	75	80	84	93	92	92	93	93	90	84	92
high ¼	92	82	88	95	97	96	97	97	98	97	95	98

Table VIII — Distribution of "P" Values of Alloy Steel Parts

"P" Value	Pitman Arm and Bell Crank				Crankshaft Bearing Cap Screw					Spring Clips		
	1300	4000	8700	9400	1300	4000	4100	8700	9400	1300	4000	9400
80		1										
82		—										
84	1	1										
86	2	—		2								
88	3	1	1	—								
90	5	1	1	6								
92	3	4	2	6							1	3
94	4	4	—	6	1				2		—	3
96	2	9	2	3	1	1	4	3	2		—	3
98		5	2	4	2	2	1	3	7		—	13
100		5	2	22	3	7	8	9	18	5	2	11
102		3	2	42	5	5	4	17	9	13	—	34
104		1	4	15	10	7	10	16	10	20	5	27
106				1	6	7	3	10	11	9	3	12
108					3	3	1	2	2	2	2	3
110					6	1		1	—	5		
112					—	1			—			
114					1				3			
Total	20	34	15	107	38	34	31	61	54	54	13	106
low ¼	88	92	92	98	101	100	98	100	98	101	100	99
high ¼	94	100	104	104	108	107	105	106	106	107	108	105

the test piece is cut — largely because the hardness ranges are similar. The higher manganese and small cross section have raised the "Y" value of the connecting rod above that of the other plain carbon steel parts, but the manganese sulphide inclusions have apparently prevented a corresponding increase in the "P" factor. The impact strength of the lunette eye appears low, compared with the crankshaft and connecting rod, in spite of a lower hardness limit — which may perhaps be attributed to the slightly higher carbon content of the steel used (see Table I); however, the number of tests is hardly enough to establish this definitely.

In the alloy steel parts the tensile properties obtained on the steering gear (Pitman arm and bell crank) are considerably lower than on the other two parts on account of the smaller cross section of the latter. In the steering gear and spring clips the 4000 series shows low "Y" values, although in the bearing cap screw all steels are about equal. As regards "P" values, the 4000 steels resemble the other alloy steels. "P" values appear to be fairly independent of composition in any one part, except that the 1300 series shows low values in the larger sections, which is seen also in the low impact values, reflecting the embrittling effect of high manganese contents. The "Y" values of the 1300 steels are similar to those of the other alloy steels. In comparing the properties of the alloy steels with those of the plain carbon steels, the effect of the higher hardness of the former on the "Y" values and on the impact strength must be considered.

Table IX — Distribution of Charpy Impact Strengths of Alloy Steel Pitman Arm and Bell Crank

Charpy Impact	1300	4000	8700	9400
20 ft-lb.		1		1
22	1	—		1
24	1	1	1	6
26	3	—	2	—
28	4	2	—	6
30	3	2	1	—
32	—	4	4	4
34	3	2	—	5
36	—	3	—	18
38	1	4	1	14
40		2	1	30
42		—	1	13
44		2	—	5
46		1	—	2
48			1	
Total	16	24	12	105
low ¼	26	30	26	34
high ¼	34	40	40	42

Regarding bolts and studs too small to furnish standard tensile test specimens, it was noted that their breaking load when pulled in fixtures was equivalent to (Brinell hardness × 500 ± 5000) × (mean of pitch and root cross-sectional areas).

Revision of Specifications — The preceding results were used to advantage in rewriting the physical property specifications for these parts.

The hardness values after tempering remain unchanged in the revised specifications, except in two special cases; the lower limit of the crank-

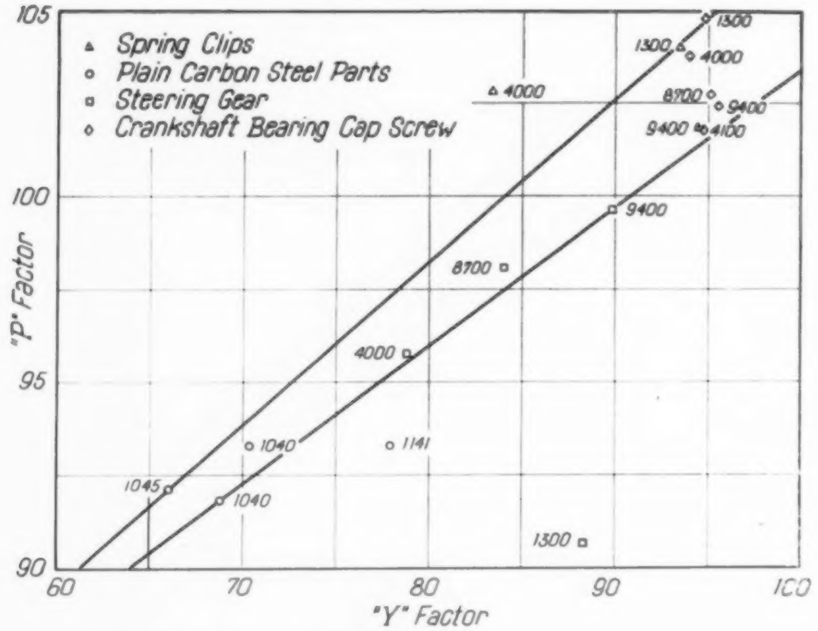


Fig. 1 — When "Y" Factors of the Steels Comprising These Tests Are Plotted Against "P" Factors, Most Points Fall Within a Rectilinear Band

shaft is raised from 207 to 212 to afford a larger margin of safety in securing the minimum tensile strength, and the maximum hardness of the spring clips is raised from 351 to 363 to reduce rejections in heat treatment. This change does not materially affect machinability, and increases rather than decreases performance. The original drawings did not show the location of the hardness readings, although their values vary somewhat from section to section and from surface to center of the part; the revised specifications show the locations of the points where the readings are to be taken.

The minimum tensile strengths in the specifications for the seven parts also remain unchanged, but maximum values are added because no minimum values for elongation or reduction of area are now specified as such; the ranges are established from the data of Tables II and VI. Yield strength and reduction of area are keyed to the tensile strength by the "Y" and "P" factors respectively, and minimum requirements only are specified, based on the values shown in Tables III, IV, VII, and VIII. In order to make the specifications more rigid while still not too restrictive, all values were established with the understanding that parts failing to meet the specification by a narrow margin would be acceptable, provided two further tests were satisfactory.

Elongation, in parts such as these, varies from about one-third the reduction of area at low hardness to one-quarter at high hardness. Specifications for elongation are therefore considered superfluous, since reduction of area and especially the "P" factor are more closely related to impact strength than is the elongation.

Specifications for impact strength are added, which had previously to be omitted due to lack of data. The Charpy keyhole specimen is preferred to the Izod triple-notch specimen, because the latter shows larger experimental errors, originating in variations in the profile of the cutters used for making the notches.

A typical specification before and after revision is given on page 85. It will be noted that, for full measure of control, a requirement for as-quenched hardness has been added. One day sufficient evidence may be obtained to show that, if the chemical analysis and as-quenched and tempered hardnesses of a piece of steel are known, its tensile properties can be accurately predicted.

Conclusions — The writing of specifications for tensile properties may be improved by adjusting the requirements for yield strength and reduction of area to variations in the tensile strength, as the latter fluctuates within certain permissible limits on account of deviations in steelmaking and

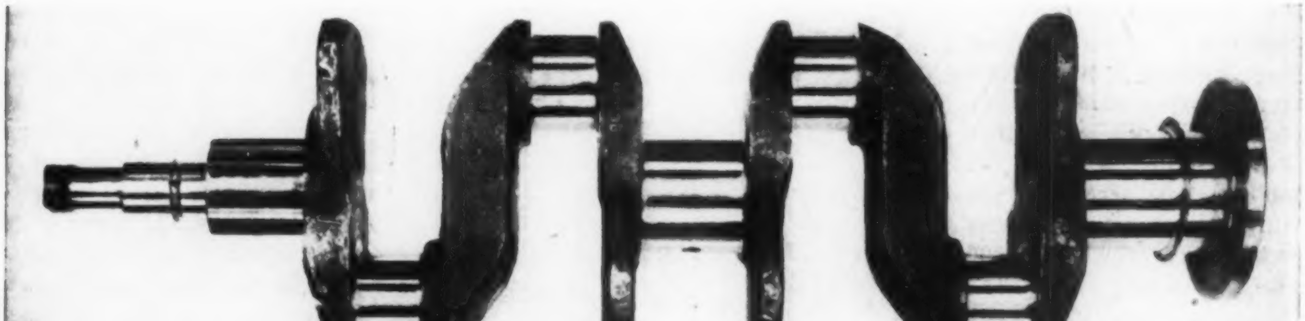


Fig. 2 — Crankshaft for "Jeep" Engine, 22½ In. Long Overall

processing. The measures of yield strength and reduction of area, as functions of tensile strength, named respectively the "Y" and "P" factors, are almost independent of final hardness after hardening and tempering a given piece, and therefore permit a comparison of tensile properties in parts tempered to different hardness levels. In this way it is found that — particularly in small sections — the various grades of alloy steel tested are substantially equivalent. Sufficient data were frequently unavailable to draw definite conclusions, so the *method* described here should be emphasized as much as the specific *results*.

Specifications for Connecting Rod

Original Specification

Material
Hot rolled steel, fine grain size, A.I.S.I. C1141

Heat Treatment
Harden in oil and temper to 228 to 255 Brinell

Physical Properties

Tensile strength	100,000 psi. min.
Yield strength	75,000 psi. min.
Elongation in 2 in.	20% min.
Reduction of area	50% min.

Revised Specification

Material
Hot rolled steel, fine grain size, A.I.S.I. C1141

Heat Treatment
Harden in oil and temper to 228 to 255 Brinell on flashline of boss
Quenched hardness Rockwell C-37 min. at center of test bar

Physical Properties
Test bar: ¾-in. min. square forging, heat treated with parts

Tensile strength	100,000 to 120,000 psi.
Yield strength (min.)	Tensile × 70%
Reduction of area (min.)	(71-Tensile ÷ 6000)
Charpy impact (min.)	28 ft-lb.

A graph of average "P" versus "Y" factors (see Fig. 1) shows that 13 of the 16 points for the different steels and parts tested fall within a reasonably narrow rectilinear band. This result appears somewhat surprising inasmuch as the "Y" factor increases slightly with tempered hardness while "P" remains almost constant. If substantiated by further data, such a curve or band would enable the yield strength and reduction of area to be predicted with some accuracy. Alternatively, if the tensile properties are known, the curve can be used as a yardstick for measuring response to heat treatment, the degree of response can be judged by position along the curve, and abnormalities can be detected by distance from the curve. ●

A department for minor items — short cuts and labor-savers in plant and laboratory. An ● book of your own choosing for acceptable items

BITS AND PIECES

Size Stabilization

SUBZERO treatment of steels at −120° F. has been established as a valuable supplement to heat treating high carbon, high alloy and high speed toolsteels. But one of the biggest time-saving applications is the dimensional stabilization, which can be held to such close tolerances as 2 micro-inches. This is extremely important in the manufacture of precision instruments, and also applies to the close tolerances of many parts. Fabrication may call for 0.0001-in. tolerance, but the part may grow beyond this limit after it has been finished, even when precautions have been taken to relieve internal stresses.

An instance is a grinding machine spindle of carburized nickel steel. It retained so much austenite in the skin after oil quenching and tempering that some of it transformed to martensite when the machine in which it was installed operated under normal speeds and loads. The spindles grew in size and bound. This trouble was eliminated by "sub-zeroing" the parts before finished machining — cooling the spindles to −150° F. accelerated the austenite → martensite reaction (with its associated expansion) and size was stabilized before final finishing. (AVERY C. JONES, field engineer, Bowser, Inc.)

To Avoid Staining Around Cracks

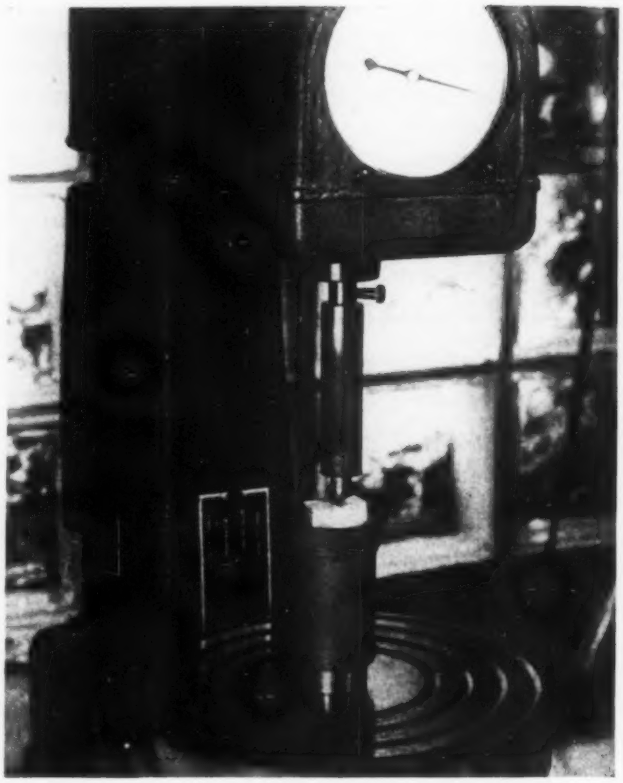
IN TAKING photomacrographs of welded sections I have found that it is difficult to obtain a clear surface of the specimen. In spite of careful rinsing after etching, acid inevitably seeps from the cracks or tight joints of the weld when such are present, and stains the etched surface of the specimen while it is under the camera.

The following method of preventing stains was found to be very helpful: The specimen was etched with 50% HCl, washed with water, and submerged in 20% NaOH to neutralize any trace of acid and was photographed while still under the solution. In other words, a shallow beaker or container is placed on the (vertical) microscope or camera stand, and enough NaOH solution poured in to submerge the specimen. Three wads of plasticene modeling clay, under the beaker, will assist in bringing the surface to be photographed perpendicular to the optical axis.

This method gives successful results, eliminating a great deal of rinsing and drying, and insuring an unstained surface of the specimen. (Victor Kappel, president, Connecticut Metal Treating Co.)

Hot Hardness Testing

THE UNIT developed by Edward C. Bishop and Morris Cohen (*Metal Progress,* March 1943, page 414) for directly determining the Rockwell hardness of high speed steel at elevated temperatures has been simplified for routine work in the steel mill.



The photograph shows the downward "Brale" extension (made of a high strength stainless steel known as 19-9DL, containing 19% Cr, 9% Ni, 1.5% W, 1.5% Mo, 0.5% Cb, 0.5% Ti), the specimen resting in a guide ring, and the anvil extension (also made of 19-9DL). A copper plate was brazed to a hoop around the 8-in. testing table and cooling water was passed through the chamber so formed; in this way the elevating screw was kept cold and the oil did not congeal on the ball bearings. Likewise a closely nested flat coil of copper tubing, resting on the top of the furnace, protected the depth dial and other mechanism at the top of the Rockwell machine.

A Rockwell hardness tester of 12-in. vertical capacity was used to permit a large enough furnace for temperature uniformity over the specimen and the Brale. Such a furnace has an outer casing about 6 in. in diameter by 6 in. high; ends are flat transite slabs. One thermocouple in the winding is used to control the furnace temperature through a Micromax with program control, and another is passed through the furnace walls into a hole in the specimen, whose temperature is registered on a recording potentiometer. Nitrogen is fed through a hose entering the furnace bottom, to permit readings to be taken at 1500° F. without excessive deterioration of the special mounting of the diamond. ("H" series Brales were developed by the Wilson Mechanical Instrument Co. for this work.) The heating chamber consisted of an 18-8 tube, 3 in. i.d. by $\frac{3}{16}$ in. wall, 6 in. long, wound with 18-gage Chromel A wire (resistance of 8.5 ohms, cold). As noted above, the furnace cover is water cooled by a flat coil of copper tubing, and is fitted into a trough wide enough for ¾ in. of motion over the specimen.

Typical results with this equipment are given in the table below. (Otto Zmeskal, director of research, Universal-Cyclops Steel Corp.)

High Temperature Hardness of Various Alloy Steels

Steel	70° F.	1000° F.	1200° F.	1400° F.	Scale
High speed steel (6% W, 6% Mo, 2% V type)	64	56	47		C
Hot work steel (12% Cr, 12% W)	47		27		C
Valve steel (21% Cr, 12% Ni)	38		26	18	C
Hot work steel (5% Cr, 1% Mo, 1% W)	58	47	18		C
Cold work steel (5% Cr, 1% Mo)	64	44	25		C
High strength stainless (19-9DL)	34	21	14	1	C
WC with 12% Co binder	88	88	86	83	A

Identification of Nickel or Monel Wire in a Woven Wire Screen

IN THE PAST, there has been no method of determining the presence of nickel or monel wire in a woven wire screen without the destruction of the screen by numerous tests on individual wires or by elaborate and expensive magnetic or electrical tests. The following short chemical method of determining the presence of nickel or monel in such a woven screen, without damage, has been developed at our plant. It involves a positive test for the copper in the monel wire.

The screen is cleansed to remove any oily film present, also to activate both monel and nickel wires. The cleansed area is then dipped for 2 sec. into a 50% solution of nitric acid. (The excess acid must be removed completely from the interstices and mesh intersections, as this would cause interference by the formation of copper salts on all wires.) The acid coating is allowed to react to completion.

The wires of the screen will, upon drying, be coated with a layer of salts — the nickel with nickel nitrate, the monel with both copper and nickel nitrates. The screen is then dipped into a 1% solution of potassium ferrocyanide, $K_4Fe(CN)_6$, and is allowed to dry in the air.

After drying the monel wires will be covered with a deep pink-colored salt. This is copper ferrocyanide, $Cu_2Fe(CN)_6 \cdot 7H_2O$, and is not present on the nickel wires. Nickel ferrocyanide, $Ni_2Fe(CN)_6 \cdot xH_2O$, will also be present on the monel wire, but its characteristic color is effectively masked by the copper salt.

The nickel wires will be colored with the slightly green tinted salt of nickel ferrocyanide. The reaction on the nickel wires is similar to the nickel reaction on the monel wires.

Both the copper and nickel ferrocyanide salts may be removed by an ammoniacal wash. Except for the slight etching action of the nitric acid, the screen will not be damaged. (ROBERT L. HACKNEY, C. O. Jelliff Mfg. Corp.)

Etching Reagent for Stainless Steels

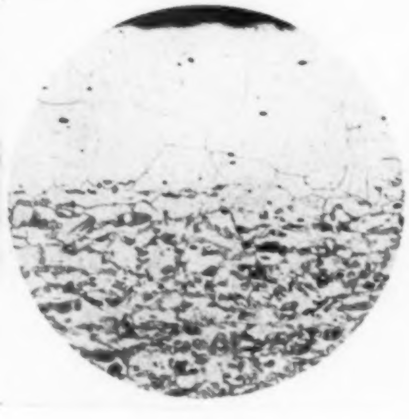
FOR the past two years we have successfully used aqua regia saturated with cupric chloride as an etching reagent for stainless steels and irons. Made up and used as described, the etch is easily controlled and lends itself especially well to the etch, repolish and re-etch method of preparing stainless microsections. As an etch for structure it is very effective in bringing out grain boundaries and twinning in annealed alloys.

The following proportions are suitable:

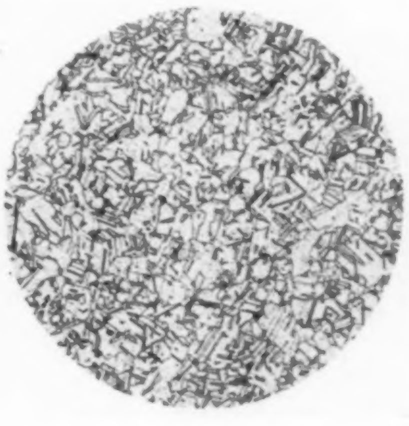
7 to 8 ml.	HNO_3
2 to 3 ml.	HCl
0.5 g.	$CuCl_2$

The cupric chloride is added in excess and the amount can be estimated. Use clear cold acid and mix in a dry dish at not over 80° F. Stir a few times and etch immediately by swabbing with clean cotton saturated with the reagent. Etching time is from 5 to 20 sec. Three representative micros are reproduced at the bottom of the page.

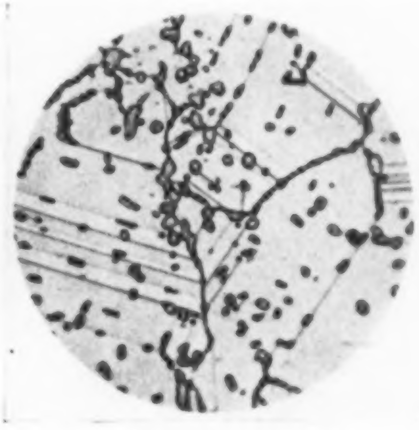
The solution does not keep and should be discarded within 1 to 2 min., for when fuming begins the etch can no longer be controlled. Rinsing the etched specimen with a soap solution helps to avoid stains. (ROBERT A. HUSEBY, research metallurgist, A. O. Smith Corp.)



Type 405 (12% Cr, 0.08% C) at 50 ×. Decarburized skin over two-phase structure



Type 347 (18-8 Cb) at 75 ×. Twinned austenitic grains in cold drawn and annealed tube

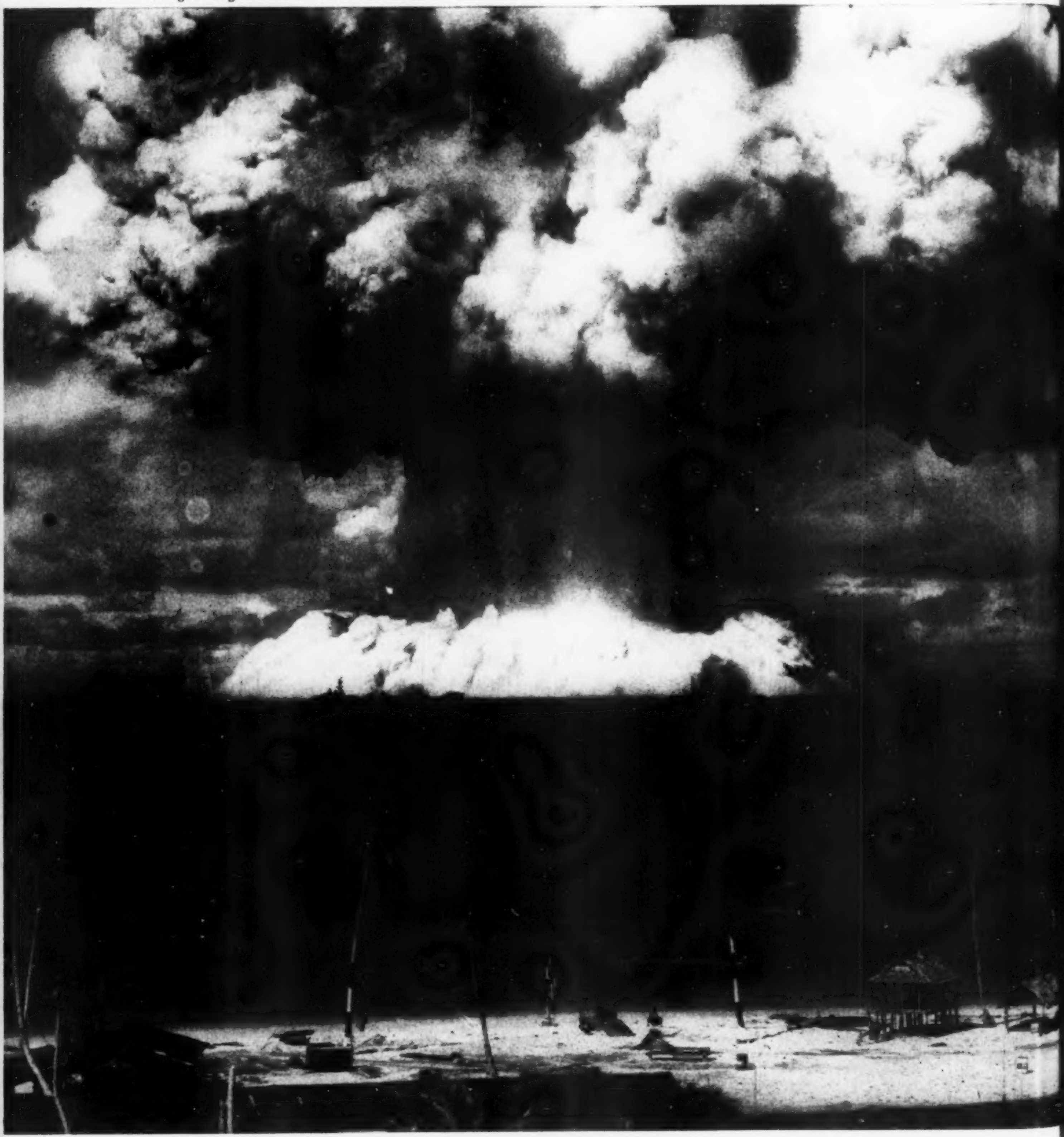


Hastelloy C (17-14-5-6-58 Mo-Cr-W-Fe-Ni) at 750 ×. Stabilized at 2050° F.

Baker Day at Bikini

A Plan

Joint Army-Navy Task Force One Photo



for Controlling Atomic Energy and Weapons

ON November 13 the United Nations Atomic Energy Commission, taking note of some five months of ineffectual discussion, resolved by a vote of 10 to 0 (Russia and Poland abstaining) to report its recommendations to the Security Council not later than December 31.

On December 5, BERNARD M. BARUCH submitted definite "proposals by the United States's representative of certain items to be included among the findings and recommendations to the Security Council", and these proposals were adopted unchanged on December 30 by a vote of 10 to 0 (Russia and Poland again abstaining). The complete document submitted to the Security Council on December 30 runs to 89 pages, principally consisting of a review of known facts about atomic energy, prepared by the technical advisers.

Text of the summary findings and recommendations — slightly condensed — is as follows:

1. That scientifically, technologically and practically it is feasible *(a)* to extend among "all nations the exchange of basic scientific information on atomic energy for peaceful ends",* *(b)* to control "atomic energy to the extent necessary to ensure its use only for peaceful purposes",* *(c)* to accomplish "the elimination from national armaments of atomic weapons",* and *(d)* to provide "effective safeguards by way of inspection and other means to protect complying states against the hazards of violations and evasions".*

2. That effective control of atomic energy depends upon effective control of the production and use of uranium, thorium and their fissionable derivatives. Appropriate mechanisms of control to prevent their unauthorized diversion or clandestine production and use, including inspection, accounting, supervision, licensing and management, must be applied through the various stages of the processes from the time these minerals are severed from the ground to the time they become fissionable materials and are used.

3. That, whether the ultimate fissionable product be destined for peaceful or destructive uses, the productive processes are identical and inseparable up to a very advanced stage of manufacture. Thus, the control of atomic energy to ensure its use for peaceful purposes, the elimination of atomic weapons from national armaments, and the provision of effective safeguards to protect complying states against the hazards of violations and evasions must be accomplished through a single unified international system of control.

4. That the development and use of atomic energy are not exclusively matters of domestic concern, but rather have predominantly international implications.

5. That an effective system of control must be

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*Quotations are from the resolution providing for this Commission, passed by the General Assembly of United Nations on Jan. 24, 1946.

international in scope, and must be established by an enforceable treaty administered by an international agency within the United Nations, possessing adequate powers and properly organized, staffed, and equipped for the purpose. Only by such a system of international control can the development and use of atomic energy be freed from nationalistic rivalries with consequent risks to the safety of all peoples, and the benefits of widespread exchange of scientific knowledge and of the peaceful uses of atomic energy be assured.

6. That an international agreement outlawing the production, possession and use of atomic weapons is an essential part of any such system of international control of atomic energy. An international convention to this effect, if standing alone, would fail *(a)* "to ensure" the use of atomic energy "only for peaceful purposes"* and *(b)* to provide "for effective safeguards by way of inspection and other means to protect complying states against the hazards of violations and evasions".* To be effective, such an agreement must be an integral part of a treaty providing for a comprehensive system of international control and must be fortified by adequate guarantees and safeguards in the form of international supervision.

Based upon these findings the Commission makes the following recommendations to the Security Council, which recommendations are interdependent and not severable:

1. There should be a strong and comprehensive international system of control and inspection aimed at attaining the objectives set forth in the Commission's terms of reference.

2. Such an international system of control and inspection should be established and its scope and functions defined by a treaty or convention in which all of the nations members of the United Nations should be entitled to participate on fair and equitable terms. The international system of control and inspection should become operative only when those members of the United Nations necessary to assure its success have bound themselves to accept and support it.

3. The treaty or convention should include, among others, provisions

(a) Establishing, in the United Nations, an International Authority possessing powers appropriate for the prompt and effective discharge of the duties imposed upon it. Its rights, powers, and responsibilities should be clearly defined, and should be sufficiently broad and flexible to deal with new developments that may hereafter arise. The treaty shall provide that the rule of unanimity of the permanent members, which in certain circumstances exists in the Security Council, shall have no relation to the work of the Authority. No Government shall possess any right of veto over the fulfillment by the Authority of the obligations imposed upon it nor the power to obstruct the course of control or inspection. The Authority shall promote the exchange of basic scientific information on atomic energy for peaceful ends, and shall be responsible for preventing the use of atomic energy for destructive purposes.

The Authority should have research and developmental responsibilities in order to remain in the forefront of atomic knowledge. The exclusive right to carry on atomic research for destructive purposes should be vested in the Authority. Research in nuclear physics having a direct bearing on the use of atomic energy should be subject to appropriate safeguards, which should not interfere with the prosecution of pure scientific research, or the publication of its results, provided no dangerous use or purpose is involved.

Decisions of the Authority, pursuant to the powers conferred upon it, should govern the operations of national agencies for atomic energy. The Authority should interfere as little as necessary with the operations of national agencies for atomic energy, or with the economic plans and the private and state relationships in the several countries.

[The treaty should also include provisions]

(b) Affording the duly accredited representatives of the Authority unimpeded rights of ingress, egress and access for the performance of their inspections and other duties into, from and within the territory of every participating nation, unhindered by national or local authorities.

(c) Prohibiting the manufacture, possession, and use of atomic weapons by all nations parties thereto and by all persons under their jurisdiction.

(d) Providing for the disposal of any existing stocks of atomic weapons and for the proper use of fissionable materials adaptable for weapons.

(e) Specifying the means or methods of determining violations of its terms, setting forth such violations as shall constitute international crimes, and establishing the nature of the measures of enforcement and punishment to be imposed upon persons and upon nations guilty of violating the terms of the treaty or convention. The processes for determination of violations and of punishments therefor should be swift and certain. Serious violations of the treaty shall be reported immediately to the General Assembly and to the Security Council. Once the violations constituting international crimes have been defined and the measures of enforcement and punishment therefor agreed to in the treaty or convention, there shall be no legal right, by veto or otherwise, whereby a willful violator of the terms of the treaty or convention shall be protected from the consequences of violation of its terms.

4. A violation might be of so grave a character as to give rise to the inherent right of self-defense recognized in Article 51 of the charter of the United Nations.

5. The treaty should provide a schedule for the completion of the transitional process over a period of time, step by step, in an orderly and agreed sequence leading to the full and effective establishment of international control. In order that the transition may be accomplished as rapidly as possible and with safety and equity to all, this Commission should supervise the transitional process, and should be empowered to determine when a particular stage has been completed and subsequent ones are to commence.

Analysis of stresses by electric strain gage showed that metal at the weld between circumferential flanges and shell of a small pressure vessel under working loads was stressed very close to the expected yield point of the metal simultaneously in both tangential and longitudinal directions. The author shows that these biaxial stresses can be duplicated in the neck of a notched plate specimen, tested in tension, and suggests that tension impact tests of such pieces at various temperatures would develop quantitative information about the working behavior of steel in rigid structures, and especially its transition temperature from ductile to brittle condition.

BIAXIAL STRESSES IN RIGID VESSEL SIMULATED IN NOTCHED TENSION COUPON

By GIVEN BREWER

Consulting Engineer, Laguna Beach, Calif.

DURING an analysis of the stresses in a small pressure vessel (Fig. 1), electric strain gages were placed on the weld metal joining shell and flange in pairs at various positions around the diameter and in such a way that one gage showed circumferential strains and its mate showed longitudinal strains. Strain gage rosettes were also cemented to the wall of the vessel some 2⅛ in. away from the flanged joint.

When the gages were affixed the flange bolts were loose. After the gages were connected to the indicating equipment, the bolts were tightened with wrenches exerting 100 ft-lb. torque, and the induced strains measured. Internal pressure in the vessel was then raised to 267 psi. (and later to 300 psi.) and all readings repeated. Maximum stresses found in any of the three conditions and two locations are listed in Table I, page 92. It will be noted that the critical location is apparently in the weld metal at the flange, where the stresses are two-dimensional in nature, and the two principal stresses are nearly equal in magnitude — on the order of 27,500 psi. under working conditions.

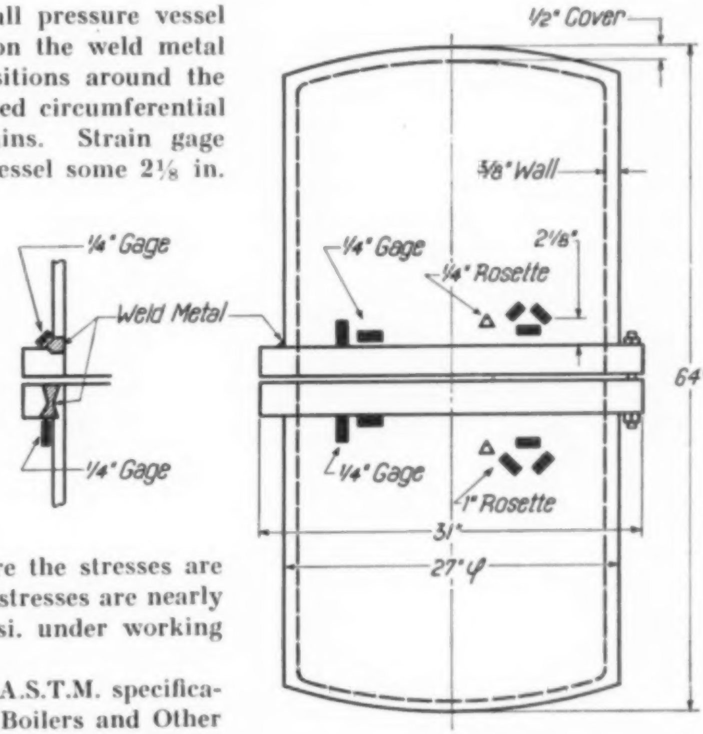

Fig. 1 — Sketch of Small Pressure Vessel Showing General Location of Electric Strain Gages

This vessel was made of steel conforming to A.S.T.M. specification A 70-44, "Carbon Steel Plates for Stationary Boilers and Other Pressure Vessels", and therefore had a minimum tensile strength of 55,000 psi. and minimum yield point of half as much (27,500 psi.). These specification figures are of course determined on standard tension test pieces where the stress is substantially unidirectional.

Table I — Maximum Stresses Found in Small Vessel

CONDITION	WELD METAL		SHELL PLATE	
	CIRCUMFERENTIAL	LONGITUDINAL	CIRCUMFERENTIAL	LONGITUDINAL
Bolts tightened	+21,800	+28,800	+11,000	−2,000
267-psi. pressure	+25,100	+28,700	+20,100	+5,000
300-psi. pressure	+25,620	+28,850	+21,100	+6,000

There was little reason to doubt that the shell plate, even as close as 2 in. to the heavy, restraining flange, was stressed dangerously in a biaxial manner (+21,100 and +6000 psi.), but it must be recognized that this same steel at the base of the weld fillet would be stressed quite as heavily as the weld itself (+25,620 and +28,850), that is to say, in two directions each of intensity equaling the minimum yield point of the material when loaded in a single direction.

Quite aside from the unpredictable action of rolled steel boiler plate when such stresses are reinforced by impact or altered by temperature, practically nothing was known about the reaction of the weld metal under such conditions. As a first step in learning something about this, two pieces of the same steel were butt welded by the same shop and technique and a small test piece shaped like Fig. 3 was prepared (width was 4 in., thickness ⅜ in.). Slots ¼ in. wide with semicircular ends were cut, leaving a neck 1 in. across, all in weld metal. Four strain gages were affixed to the neck of this coupon, two on either face, one opposing pair registering longitudinal strains and the other pair registering strains at right angles thereto.

This coupon was then pulled to destruction in tension in the usual way, and the elastic portion of the stress-strain curve indicated the presence of a very high transverse stress. Calculations made from the attached strain gages indicated ratios of transverse stress to longitudinal stress of about 0.85 on the surface midway between notch fillets.

It was not immediately apparent why a ratio of transverse to longitudinal stress greater than Poisson's ratio (roughly 0.3) could exist in the region of the notch. For this reason a photoelastic notched coupon was prepared and tested in tension in the same way by R. C. Zaller, consulting engineer. Its dimensions were: 3 in. wide, ¼ in. thick, slot 0.188 in. wide with semicircular ends, neck ¾ in. across. The distribution of stress across the neck of the notch as determined by Mr. Zaller is given in Fig. 2 and reveals a ratio of transverse to vertical stress of 7300÷9000 or about 0.80 at the coupon centerline, tending to corroborate the strain gage studies of the small steel coupon.

Due to the fact that the fringes in a photoelastic model are numerically a function of the difference between the principal stresses, few fringes existed in the central portion of the notched coupon, making an exact analysis somewhat difficult. It was therefore decided to repeat the tension test, using a larger and carefully machined steel plate and a larger number of electric strain gages.

Results of Tests

A large plate of 1050 carbon steel* was obtained and stress relieved by heating 1 hr. at 1650° F., furnace cooled to 1250° F. in 3 hr., and then allowed to cool with the furnace to room tem-

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*Triplett and Barton analysis showed 0.52% C, 0.035% S, 0.014% P, 0.71% Mn, 0.21% Si, 0.11% Ni, <0.05% Cr, <0.05% Mo.

Table II — Tensile Strains (Micro In. Per In.) in Notched Steel Plate at Various Machine Loads

GAGE	200	7500	15,000	20,000	25,000	32,000	37,000	45,000	50,000	55,000	60,000	65,000	200
1	0	− 80	−150	−300	−400	−520	−680	− 870	−1620	*	*	*	*
3	0	30	50	110	150	200	220	300	300	220	120	− 160	− 650
4	0	150	330	450	560	750	850	1070	1220	1370	1500	1700	600
5	0	50	120	160	210	260	310	400	480	560	670	680	70
6	0	90	170	230	310	400	460	570	630	730	820	870	200
7	0	100	200	280	370	460	525	620	710	800	950	1190	560
8	0	120	340	460	600	770	880	1120	1300	1550	1870	2820	1630
9	0	50	130	170	200	250	300	350	300	170	0	− 400	− 800
11	0	−120	−240	−400	−500	−650	−860	−1120	−2000	*	*	*	*
13	0	120	370	580	680	870	1050	1500	1780	2130	2550	*	3200
14	0	50	110	160	200	250	270	320	380	460	550	620	120
15	0	80	180	250	320	430	500	680	800	960	1250	2300	1450
16	0	80	200	300	370	470	570	720	850	970	1190	2400	1500
17	0	110	320	480	620	800	960	1320	1570	1850	2200	*	2550

*Skipped to prevent going off chart.

perature in 16 hr. This coupon was then machined as shown in Fig. 3. Electric strain gages of the A-7 (¼-in.) type were cemented to the neck of the notch on both sides. The gages were then wired and the test piece placed in a 300,000-lb. Baldwin Southwark machine in Triplett and Barton's laboratory, as shown in Fig. 4, page 94.

After the lead wires were soldered to the electric strain gages they were connected to an SR-4 automatic strain recorder and four runs were taken with various increments up to 65,000 lb. load, representing an average stress at the neck of 44,000 psi. Temperature compensation was achieved by utilizing an A-7 gage cemented to a 4130 round bar which can be seen in Fig. 4 taped to the left post of the testing machine.

Two standard A.S.T.M. round test pieces were cut from the right and left edges of the notched coupon after these tests. A-7 gages were cemented to opposite elements of the reduced portion, and a Peters averaging extensometer fixed at 90° to this diameter. Tension test data for the two samples checked closely, the average being shown in the small type below the engraving.

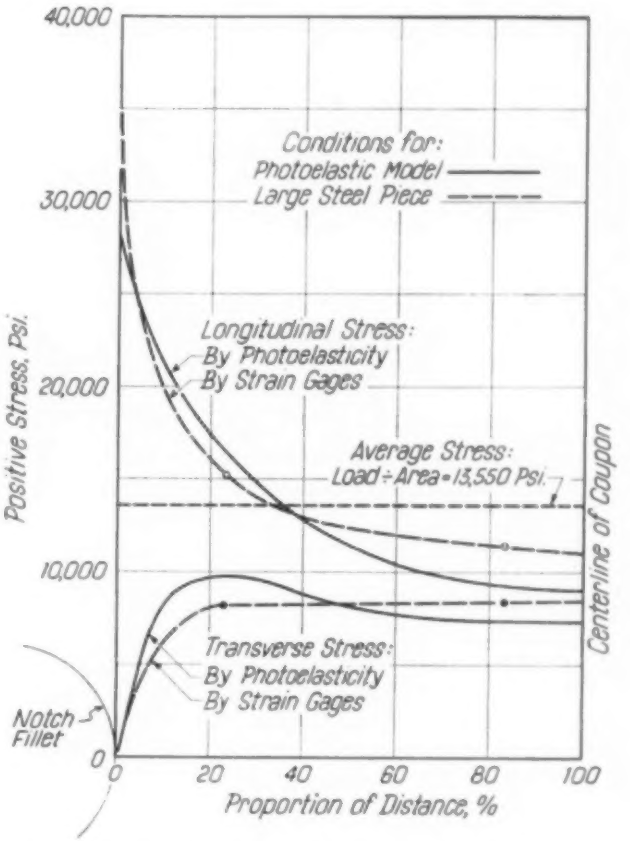
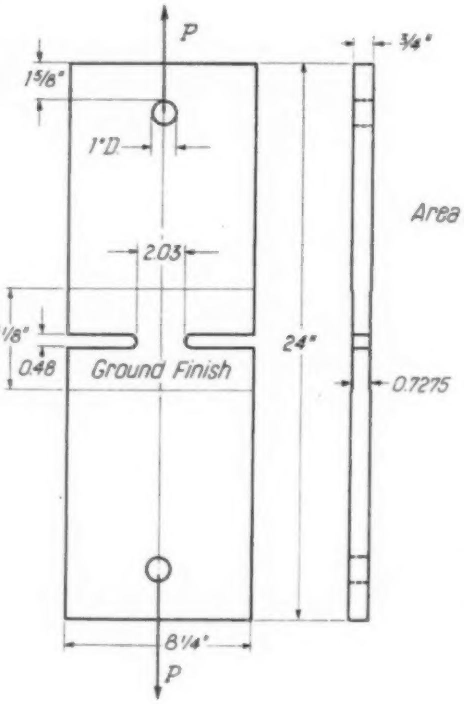


Fig. 2 (Above) — Distribution of Stress at Neck in Transparent Model and in Large Steel Plate at Total Load of 20,000 Lb.



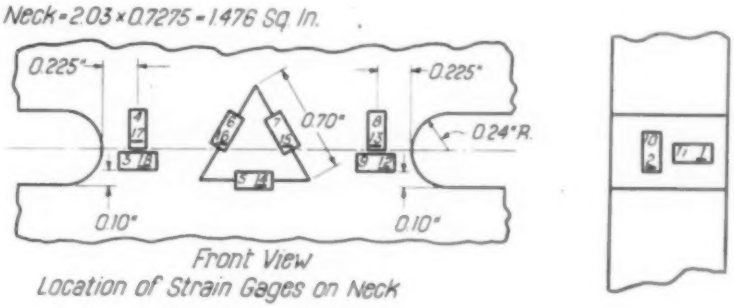

Area at Neck = 2.03 × 0.7275 = 1.476 Sq. In.
0.225"
0.225"
0.70"
0.24"R.
0.10"
0.10"
Front View
Location of Strain Gages on Neck

Fig. 3 — Dimensions of Large (Notched) Steel Test Piece and Locations of Strain Gages on Neck. (Underlined figures identify gage on far side of specimen)

Lower yield	47,750 psi.	
Upper yield	50,750	
Ultimate	97,050	(based on original area)
True strength	147,900	(based on necked area)
Elongation in 2 in.	26%	
Reduction of area	41.8%	
Modulus (gages)	31×10^6	
(Peters)	29×10^6	

In the first cycle on the notched steel plate, the total load was carried from the initial seating load of 200 lb. only up to 15,000 lb., whereupon the specimen was unloaded to the original 200 lb. All strain gages returned to their original length. The same was true of the second run, going as high as 23,000-lb. total load before release. After the third run to 35,000 and release, gages No. 1 and No. 11 (transverse, within the neck fillet) showed a compressive strain averaging 160 micro in. per in.; the other gage readings returned to zero. Readings for the fourth run to 65,000 lb. are shown in Table II on page 92; permanent strains are recorded on all gages after returning to the 200-lb. load. (Gages 2 and 10 — longitudinal in the fillet — showed such large strains during the third run that no readings were taken from them.)

Strains for the T gages near the necks were plotted and average curves drawn (Fig. 5), showing reasonably good concordance, front to back, and side to side. Figure 6 plots the readings of gages No. 1, 2, 10 and 11, within the fillet; individual readings on the four test runs are plotted, to show the general agreement, run by run.

It is to be remembered that the stresses at the center of either a T or a 60° rosette must be computed for any recorded set of strains. The formula for the T rosettes is

$$f_1 = \frac{E}{1-u^2}(e_1 + ue_2)$$

where f_n = the stress in the direction of gage n in psi.

E = modulus of elasticity (29,000,000 psi.)

u = Poisson's ratio (0.30)

e_1 = axial strain recorded by gage No. 1, in. per in.

e_2 = axial strain recorded by gage No. 2, at right angles to gage No. 1, in. per in.

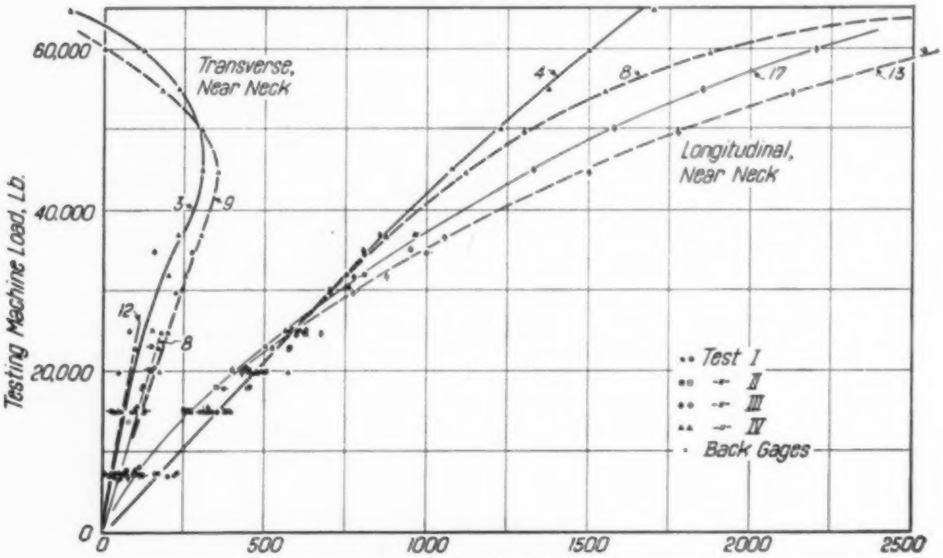


Fig. 5 — Strains Registered by Gages on Faces of Plate Near Neck

The stresses in the region of the 60° rosettes were determined by the method given by K. J. Bossart and Given Brewer in V. IV (1946) of the *Proceedings* of the Society for Experimental Stress Analysis, and corrected for cross sensitivity and for the fact that u for them is 0.30, whereas gages are calibrated on the assumption that u = 0.285.

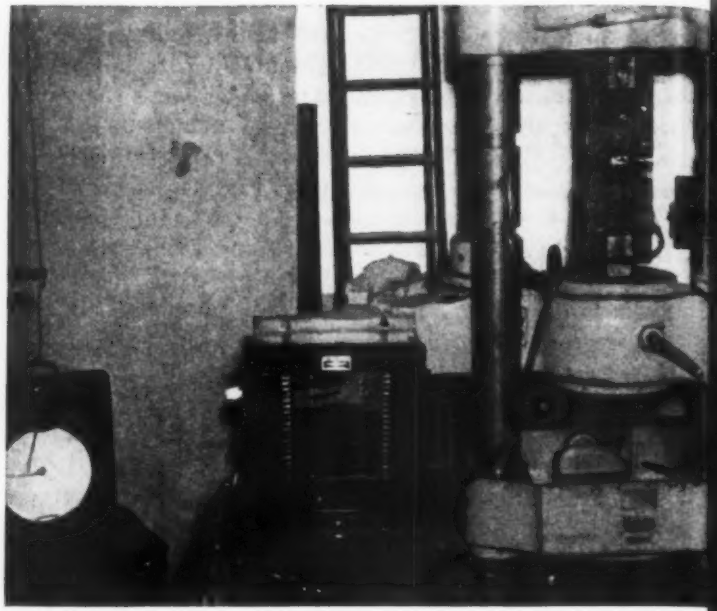


Fig. 4 — Photograph of Steel Sample in Tensile Testing Machine, Wired to Automatic Strain Recorde

Table III contains a summary of the computed stresses at the various locations for loads increasing to 40,000 psi. The distribution of stress at a machine load of 20,000 lb. is shown in Fig. 2, in comparison with the distribution as determined by photoelastic means. From Table I it is apparent that the ratio of horizontal to vertical stress f_q/f_p is about 0.70 in the central portion of the notched bar; this ratio in the photoelastic specimen is about 0.80.

Conclusions

It is concluded that notched coupons such as shown in Fig. 3 develop two-dimensional stress states in the neck closely similar to the stress state found in seams of welded pressure vessels. It is believed that, by varying the dimensions of similar coupons, the state of stress can be altered to match any condition met at any part of a rigid structure made of plate.

The moderate discrepancy between the stress distribution as determined by photoelasticity and by strain gages is accountable to *(a)* the difficulty of getting accurate fringe counts in the transparent specimen due to the low shear component of the stress state and *(b)* the fact that specimen length had not previously been considered an important factor and was not recorded.

The stresses as determined by the rosettes at the center of the notched bar are believed to be within ±2% of the true conditions, since the angle between the minor principal stress and the horizontal axis, θ, is found to be 0° or within 2° of zero at each increment of load. This is an excellent check of the accuracy of the test.

It is of interest to note, in Table II and Fig. 5 and 6, the difference between stresses on opposite faces of this carefully machined thick bar. This points up the necessity for the placement of backing gages, even on thick sheets, when great accuracy is required.

It is believed that the importance of this small investigation lies in the fact that it may provide a link between notched impact tests and the service behavior of metals. Charpy and Izod tests have

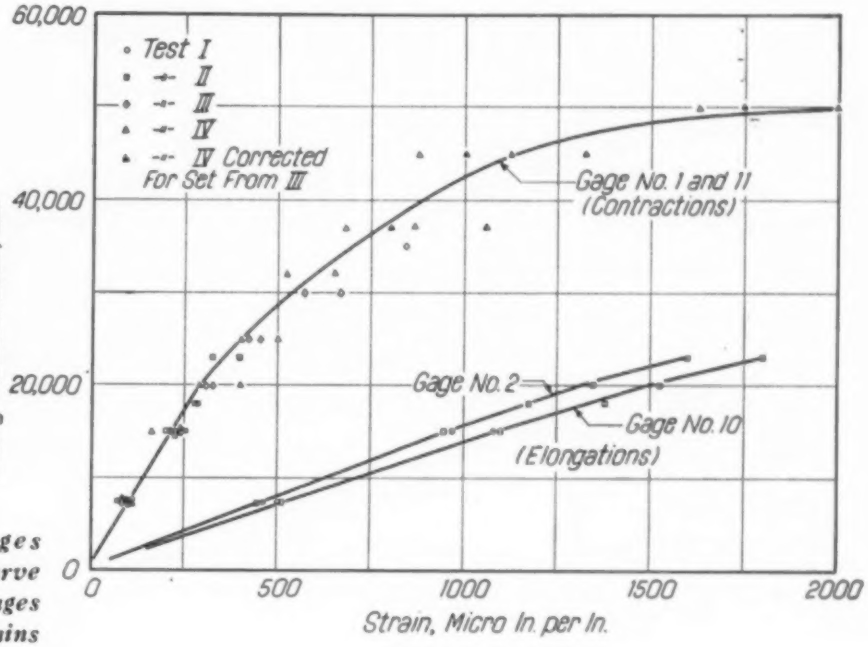


Fig. 6 — Strains Registered by Gages Inside Fillet. Note that upper curve should be reversed to left, since gages No. 1 and 11 register compressive strains

Table III — Summary of Actual Stresses for Various Machine Loads (P) and Corresponding Nominal Stresses (P ÷ A)

LOCATION OF STRESS	P = 7,500 P ÷ A = 5,080	P = 15,000 P ÷ A = 10,170	P = 20,000 P ÷ A = 13,550	P = 30,000 P ÷ A = 20,350	P = 40,000 P ÷ A = 27,100
Left fillet, vertical	13400	28170	39400		
Right fillet, vertical	15220	32950	45000		
Average	14310	30560	42200		
Left fillet, horizontal	1117	1915	3110		
Right fillet, horizontal	2392	3355	4790		
Average	1756	2635	3950		
0.225 in. from fillet					
Front left, vertical	7320	11980	16000		
Front right, vertical	7550	12350	16600		
Back left, vertical	2760	9850	14200		
Back right, vertical	2060	9050	13950		
Average vertical	4920	10800	15187		
Average horizontal	2440	5870	8097		
Approximately 0.175 in. from centerline of coupon					
Front F_p	4770		11710		23200
Front F_q	3100		8210		17200
Front θ	−11½°		−10½°		−13°
Back F_p	4300		11600		24800
Back F_q	3090		7730		16100
Back θ	17¼°		13½°		6½°
Average F_p	4450	8570	11585	16720	23550
Average F_q	3160	6050	8235	12200	16400
Average θ	0°	0°	1¼°	−1½°	0°
Photoelastic F_p	3500	7000	9340	14020	18680
Photoelastic F_q	2710	5420	7230	10870	14450

been recognized as being important, but the results therefrom have always been qualitative — at least as far as translating them into design or service figures is concerned.

When a metal is stressed the atomic lattice deforms and resists the external load in an elastic manner up to a point; beyond this, shear slip occurs along favorable planes in the metallic crystal. As shear slip continues, resistance to sliding increases until the stress has reached a point wherein separation occurs — that is, failure. In the case of triaxial tension there is no shear component of the stress state and as a result there is no slip possible in the metallic crystal. As a result the atomic lattice deforms (elastically) with applied load right up to the point where rupture occurs. On the other hand, as explained by Given Brewer and M. M. Rockwell in their article on "Stress-Strain Relationships in the Drawing of Metals" in *Metal Progress* for June 1942, it is possible to impose a stress state upon a metallic crystal wherein the shear component is very high and the separational stress very low; the metal is then capable of enormous deformations without rupturing — this being the secret of all deep drawing operations.

In welded structures, stress states are frequently encountered that are biaxial and sometimes triaxial in nature. In these structures the energy that may be absorbed by the metal without failure is very materially reduced, since the rupture stress is reached before the small shear component has reached the value necessary to cause slip. Hence, a metal under triaxial stress and impact behaves more like a piece of glass. To a lesser degree, metal under biaxial tension will have far less energy-absorbing capacity before failure than it would have under simple tension. It is therefore reasonable to assume that impact tests on notched specimens will prove to be much more valid criteria of a metal's service utility if that metal is to be subjected to biaxial stresses in service — which is quite often the case.

Maxwell Gensamer in his ⊕ book "Strength of Metals Under Combined Stresses" points out that the shear stress required for slip varies markedly with temperature, whereas the normal stress for rupture changes very little. Hence the lower the temperature the more "brittle" the behavior of the metal and, as we know that the effect of a notch is to raise the temperature where the metal changes from "ductile" to "brittle" condition, the evidence seems quite conclusive that metal under biaxial tension will be brittle at a far higher temperature than the same metal under simple tension. Also it seems reasonable to assume that since the stress state of the notched bar described in this report provides a state of stress nearly biaxial in the region of the neck, then notched specimens of this type tested under tensile impact at various temperatures should provide a quantitative measure of the ability of metal, welded or wrought, to withstand shock loads at working temperatures.

It was at first difficult to understand how a transverse stress greater than predicted by Poisson's ratio u could exist in the neck of the notch. Poisson's principle states that if a simple straight plate were rigidly restrained at the edge, yet allowed to slide vertically, an axial stress of unity, 1.0, would produce a transverse stress of only u, roughly 0.30 for steel. The explanation of this anomaly may be found by referring to Fig. 7 at left. It can be seen that, following St. Venant's principle, the stress lines are evenly spaced across the bar a short distance below the loading hole. However the stresses must crowd in at the neck and in doing so they stress the neck laterally, somewhat like the ring through which pass the supporting cords of a hammock.

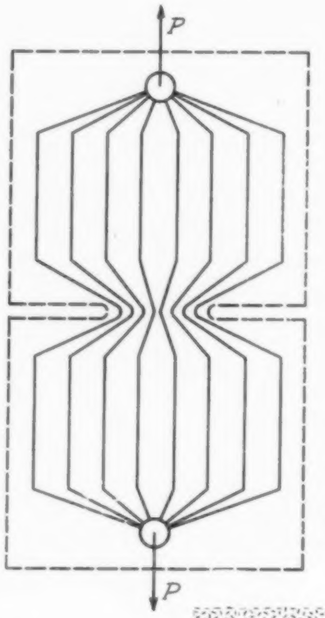
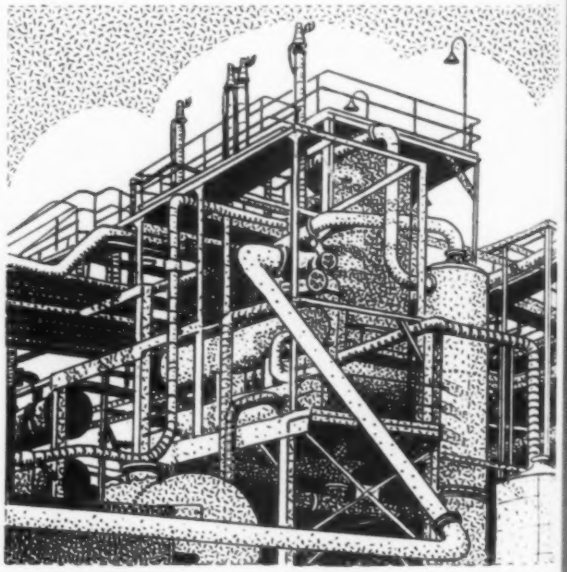


Fig. 7 — Sketch of Notched Tensile Coupon Showing Trajectories of Principal Stresses Causing Transverse Loading at the Neck



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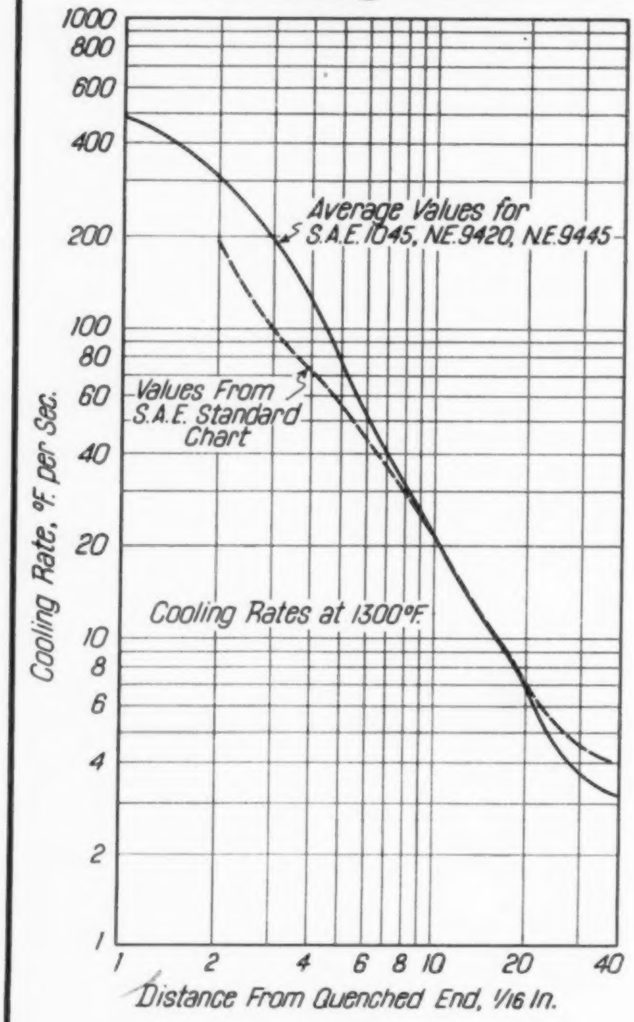
Cooling Rates of Plates and Rounds

By A. L. Boegehold and E. W. Weinman

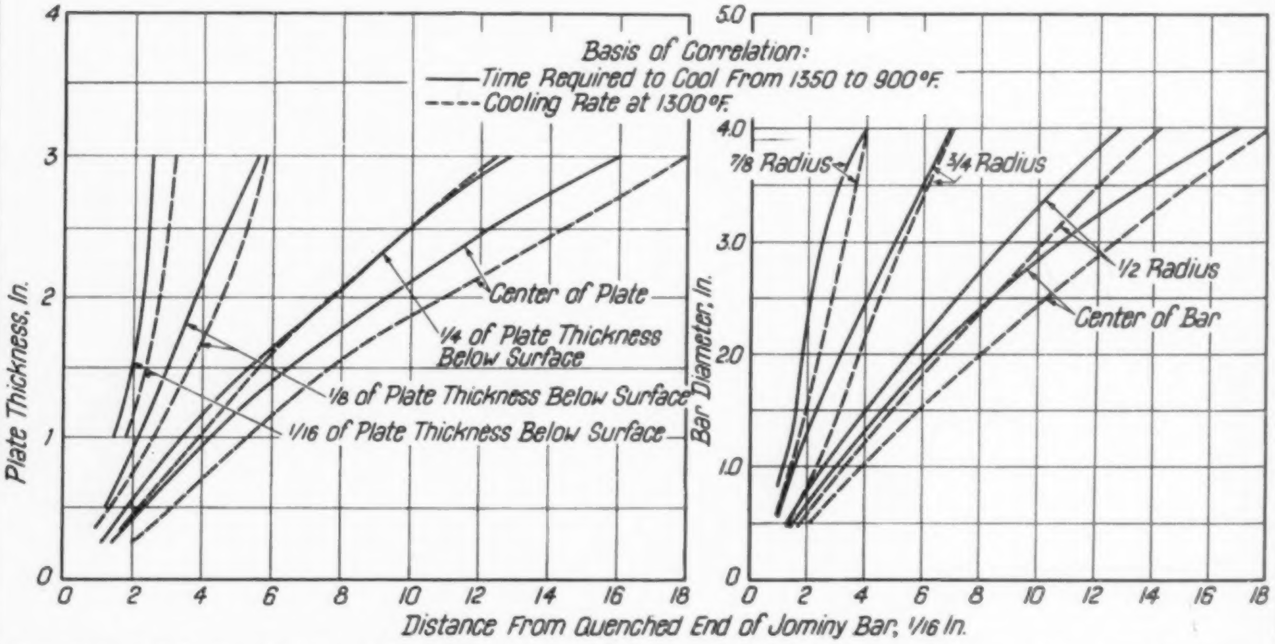
From work done under Research Contract OEM sr-1120 with the Office of Scientific Research and Development on "Heat Treatment of National Emergency Steels for Use in Tanks, Combat Cars, Gun Mounts and Other Ordnance Materiel".



Cooling Rates at 1300°F. on Jominy Bar

At Left — Revised average cooling rates at various positions on Jominy end-quenched specimens made of 1045, 9420 and 9445 steel, compared with values given on S.A.E. standard chart. Cooling rates at 1300° F. are free from influence of heat evolution during transformation, and are practically unchanged by varying the quenching temperature from 1500 to 1650° F. They are not significantly affected by slight oil contamination of the quenching water, variation in quenching jet from 15/32 to ½ in. dia., or presence of air bubbles released from solution in the quenching water.

In the curves at the bottom of the page the cooling rates at 1300° F. at various distances below the surface of plates and round bars are correlated with that position on the Jominy end-quenched bar that has the same cooling rate at 1300° F. The full lines correlate the *time* to cool various positions in the plates and bars from 1350 to 900° F. (which gives a better conception of hardenability in terms of hardness) with that position on the Jominy bar that takes the same *time* to cool through the same temperature interval (1350 to 900° F.). All tests were made on N.E.9445 or 9450 steel. Jominy bars were end-quenched from 1500° F. in the standard fixture. Plate and bar specimens were heated to 1525° F. in nonscaling atmosphere and quenched in a stream of water at 75° F. flowing at 200 ft. per min.



Correlation of Cooling Rates and Times Between Jominy Bar and Plates (Left) and Bars of Various Diameters

Bonding of metal to metal at temperatures below the melting point of either partner has long been practiced by the blacksmith. The industrial counterpart exists in the manufacture of bimetals; the one best known to Jeanne Citizen is Sheffield Plate (silver over copper); thermostatic metals are examples better known to technicians. The manufacture of compacts from powder metal, of great and growing importance, is another operation based on the same fundamental principles — principles but poorly understood, as pointed out in this review.

A FEW OBSERVATIONS ON SOLID PHASE BONDING

By GEORGE DURST

Research Engineer, General Plate Division of Metals & Controls Corp., Attleboro, Mass.

SOLID PHASE BONDING, as a principle of joining metals, is so different from flash, resistance, arc or gas welding, and from the techniques of soldering and brazing, that a brief definition is appropriate. Both the last named groups of methods use a liquid metal as a bonding agent; in other words they are fusion processes. All of them differ from a much older art of joining metals which produces durable joints by applying heat and pressure alone (and which must be considered the forerunner of modern powder metallurgy and pressure welding methods). The joining of two pieces of metal without adding or otherwise producing a liquid phase at the interface is called "solid phase bonding" or, in general, "pressure welding".

Pressure welding is feasible between identical metals and between dissimilar metals at suitable temperature and pressure. It is commonly held that cleanliness of the surfaces is a prerequisite for obtaining a good bond. It is generally agreed that the mechanism of pressure welding is based on the diffusion process and that the pressure is chiefly a means to bring the two surfaces close enough together to get within the range of atomic attraction. This assumption implies that every conceivable combination of metals will probably be pressure weldable since some diffusion occurs even between two metals which are considered to be "insoluble" in each other. However, this does not mean that pressure welding is a practical process in all cases. Many metals form intermetallic compounds at the interface, which as a rule cause brittle layers preventing the manufacturing of, or at least the fabricating of, clad metals. Also, it might sometimes be very difficult to eliminate surface films. All the same, it seems probable that there are no two metallic surfaces incapable of producing a pressure weld — provided one can overcome these natural obstacles.

Thin but tough surface films like oxides and gas absorption films, as normally present on metallic surfaces, are in general sufficiently insulating to prevent diffusion, thereby hindering pressure welding. Atomic attraction is weak beyond one interatomic distance; thus gas films, believed to be monomolecular, are an effective stop-off.

However, absorption films can be eliminated by heat, while hot oxide films, as a rule, grow in thickness unless oxygen is completely absent from the environment. How much of an obstacle is an oxide or a gas absorption film? What temperatures and pressures are required for producing a solid phase bond? Some answers to these questions can be gathered from the literature, to which brief references are made in the following. To clarify specific questions a few experiments are added. In general, no attempt is made to discuss the practical problems of metal cladding nor even to discriminate between incipient "sticking" and a good solid "bond". What is presented here is merely a random sampling of certain interesting facts, more or less closely related to the problem of solid phase bonding.

Solid Phase Bonding at Low Temperatures

A bond, in the sense of this discussion, is defined as the sticking of two metals which, when separated, show at least a microscopic fracture. It has been stated by R. S. Dean in his book on "Theoretical Metallurgy" that welding could be done at room temperature if it were not for absorbed gas. The truth of this has often been proved with soft metals like gold, silver and tin.

The following experiment at our laboratory demonstrated the cold pressure welding of copper to copper and nickel to nickel on a miniature scale. A flat and a pointed specimen were annealed by induction heating at approximately 1800° F. for 10 min. and subsequently cooled in a vacuum of $3 \cdot 10^{-3}$ mm. of mercury. The pointed part was held by a solid steel cylinder which was kept in a floating position by Alnico magnets outside a Vycor tube, as shown in Fig. 1. The magnets enabled us to drop the point to the flat piece and to lift the latter from its quartz support if a weld strength exceeding its weight was obtained. The test could be repeated by shaking the flat piece loose and choosing a new point of contact. With a steel cylinder weighing 120 g. dropping 1 in. onto a flat piece weighing 3 g., the test succeeded two times in five if both parts were copper, and three times in five if both parts were nickel.

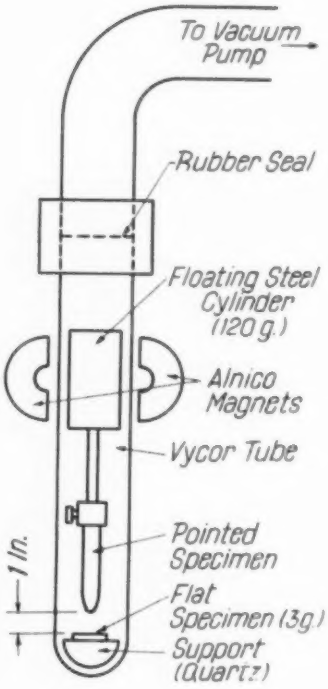


Fig. 1 — Experimental Device for Proving the Possibility of Welding Copper to Copper at Room Temperature

Elimination of the absorption film as in the above experiment does not appear necessary for bonding at room temperature under great shear stress. In fact, even metals whose hardness and whose recrystallization temperature is much higher than that of gold and silver can be cold welded under shear stress (rubbing) — particularly nickel and iron show this tendency if the metal is well degassed. (Aluminum, too, can be "cold welded" in the test to be described, particularly if the metal is in the cast condition; however, only a little bond strength is obtainable with aluminum of technical purity.) An illustrative experiment can be done as follows:

One of the knurled jaws of a heavy vise is shimmed off with a soft metal sheet to make this side smooth. Two metal specimens are strongly clamped in this vise. The one adjacent to the shim is driven along the other with a blunt punch and a hammer — a method producing considerable shear stress. Welds can thus be obtained which, although not continuous, require a chisel for destruction. Whether the welding in this case is aided by slip planes, by a "vitreous" metal phase, by frictional heat, or by a combination of factors, is still open to debate, as far as the writer knows.

It should be emphasized, though, that shear stress — a kind of unsymmetrical pressure — is different from hydrostatic pressure on which the laws of heterogeneous equilibrium are based. It is a very important factor in certain types of pressure welding that use upsetting or rolling.

Aluminum can be pressure welded satisfactorily only under shear stress, independent of the welding temperature, due to the extremely tough though invisible oxide film which fortunately can be easily broken up by rolling, forging or upsetting. Pressing without any lateral movement will not destroy it sufficiently. It is said that industrial processes were in use in Germany, employing extremely great rolling reductions at a fairly low temperature to produce a bond between aluminum foil and low carbon steel. In the light of experience we may assume that the shear stresses set up in this method broke up the oxide film and cold welded the aluminum to the iron.

Furthermore, one has to visualize the phase changes that may occur in small regions under high pressure (and the rapid succession of pressure changes under shear) to appreciate the possibility of irreversible changes. This subject is discussed in Chapter 14 of Cecil H. Desch's book "The Chemistry of Solids". Also, the fact should be considered that the diffusion constant may take on very high values if the activation energy near an interface is increased. Sudden changes in the diffused quantity of a material, point to point, are understandably caused by phase changes, but they were also observed with transformations and with recrystallization. An illustration is the greater ease of pressure welding certain metals in the work hardened condition as compared with the fully annealed material. Although some of these facts have been observed frequently, a comprehensive interpretation from the viewpoint of solid phase bonding was given only in 1944 by A. B.

Kinzel in his Adams Lecture before the American Welding Society on "Solid Phase Welding".

It has been suggested that cold welding under shear is in reality caused by frictional heat. Well known examples, like shafts "frozen" to bearings, and metallic "pickup" on drawing dies, seem to bear out this theory; however, the temperature increase depends on the sliding loads and speeds. In the tests described in the above (low speed of sliding in metal merely gripped in a vise) the momentary temperature rise is probably of a low order — too small to reach sintering temperatures. An interesting discussion of "The Ploughing and Adhesion of Sliding Metals" was printed in *Journal of Applied Physics* for February 1943, written by F. P. Bowden, A. J. W. Moore and D. Tabor.

Films Under Heat and Pressure

Let us now consider metal surfaces coated with a thin oxide film. It is a well-known fact that these thin films can often be eliminated under practical working conditions. The mechanism in this case too is diffusion. The following is an illustrative statement by A. B. Kinzel in his A.W.S. lecture: "The time-temperature conditions should be such that the concentration of the nonmetallic constituent (oxygen in most cases) is reduced to the maximum value of solid solution, and is sufficiently below that value so that reprecipitation on a plane will not occur due to decreased solubility with lower temperature."

While the role of pressure in mechanically breaking up oxide films has frequently been pointed out, little is known of the effect pressure has on their diffusion. Kinzel notes some indications of a relationship between the diffusion constant and pressure that might enter here, together with various other factors. Broadly speaking, one may assume that pressure will oppose the *dissociation* of an oxide, while it will increase, on the other hand, the *solubility* of oxygen in the metal. However, it is questionable whether an oxide at an interface, particularly when under high pressure, is in a condition that permits us to picture it in terms of gas-solid equilibria. In any event the changes in the films under consideration must be governed by the greatest possible decrease in free energy. Thus, copper oxide with its relatively low energy of formation lends itself more readily to dissociation and diffusion than, for example, nickel or zinc oxide; refractory oxides, of course, are out of consideration entirely.

The writer is not aware of exact experimental proof of the effect of pressure on film diffusion, but he has observed that the speed with which copper oxide disappears from a copper interface at bright red temperature seems to increase with higher pressures. This qualitative observation requires precise verification.

Of course, both constituents of an oxide diffuse. This can be demonstrated with a thin copper oxide film between two pieces of fine silver. Pressing such assembly, after heating it to about 1600° F. in air, produces only a weak bond — but no trace of copper oxide or copper remains visible.

The behavior of thin oxide films under pressure welding conditions is obviously of great importance in metal cladding. In most metal cladding methods thin oxide films are necessarily produced, even in tightly sealed assemblies, due to the small volume of air trapped inside such packs. There is little doubt that diffusion of these films at elevated temperature, perhaps aided by pressure, eliminates them either completely or to such degree that they cannot harm the bond.

From the oxide film it is only a small step back, in magnitude, to gas absorption films. We shall touch here only very briefly on their behavior under heat and pressure at an interface where, as pointed out before, conditions are likely to be different from the classical concept of gas-solid systems. The reason for this is the limited gas supply from a molecular film whose diffusion will raise the gas concentration in the metal but little. The effect of heat and pressure on the dispersion of absorption films is well illustrated by data obtained for silver by A. Butts and G. R. Van Duzee ("Silver in Industry", Reinhold Publishing Corp.). They proved that *(a)* a high pressure, without previously heating the silver to remove the absorption film, or *(b)* a low pressure if such preheating was done, permits welds of identical strength. They also present data on the time-temperature relationship at constant pressure, and time-pressure relationship at constant temperature, indicative of the role of plasticity and diffusion in pressure welding.

The Stirring Test

A well-known test described a generation ago in Gustav Tammann's "Text Book of Metallography" demonstrates the behavior of loose but hot metal powders under stirring at constant force with a paddle. Under these conditions various metal powders adhere *suddenly,* within a well-defined temperature range, stopping the stirrer. Duplicate results are usually in surprising agreement. The phenomenon is puzzling, since there is no known property of metals that could be associated with "sticking temperatures" — which may be nearly identical for widely different metals! While the originators of this test apparently

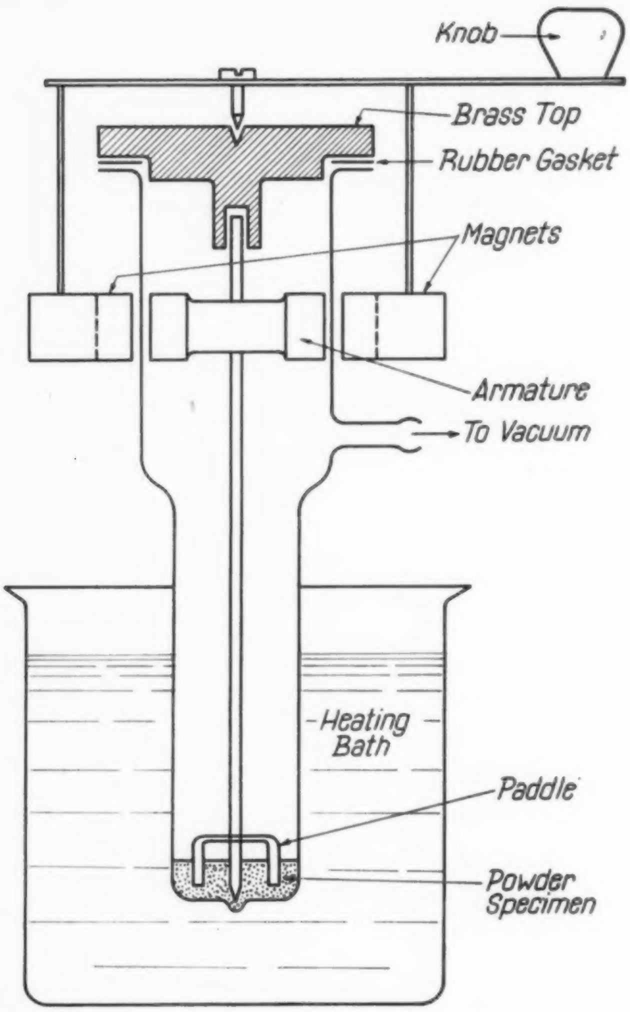


Fig. 2 — Equipment for Making the Stirring Test Under Controlled Atmosphere

had the opinion that the sticking is an early stage of sintering, induced by the abrasion of the surface films on the powder, various reasons against such assumption were voiced by W. D. Jones in his "Principles of Powder Metallurgy". Furthermore, F. N. Rhines suggested that something not closely related to the individual metal is the cause of the sticking — such as the removal of absorbed gas.

We thought, therefore, that a stirring test done in vacuum would shed light on solid phase bonding in general. Our apparatus is sketched in Fig. 2. Two strong magnets rotate outside a tube and act on an armature inside that is mounted on the vertical stirring shaft. The constant torque of 45 g-cm. thus produced acts on two vertical paddles 2.5 mm. wide. This distance between the center lines of paddles and shaft is 12.5 mm. The volume of powder that is used gives a depth of immersion of 6 mm. before starting rotation. The results of a representative series of tests are shown in the table, which notes the temperature at which the stirrer stopped.

Comparing the results, one can see that sticking requires much higher temperatures in vacuum than in air. Hydrogen, in the experiments with copper, requires an intermediate temperature. If any of the above powders is heated to below sticking in vacuum but above sticking in air, and air is let into the system, the stirrer will stop immediately. Also, powder sticking in air will loosen up in vacuum. The same sample of powder will undergo several of these reversible changes.

These results are curious enough to be recorded. One might think that the adherence of the powder in this test is caused by films, rather than by contact between metallic surfaces!

Solubility and Diffusion — Before the war the rolled gold plate industry in continental Europe used solid phase bonding methods almost exclusively. Their general experience was often expressed this way: The less mutual solubility exists in the two components to be bonded, the easier is the job. In other words, metals that are "insoluble" (like silver and iron) or little soluble (like silver and nickel) permit a large margin in temperature, pressure, and time.

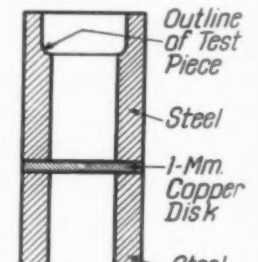
Of course, there are similar large margins in many other combinations, one partner of which is a precious metal or alloy. Also there are good reasons that the margin is often undesirably small with certain components. In the latter cases the main reason for close control can be the emergence of a liquid phase (for instance, the eutectic of silver and copper) at, or uncomfortably near, the required bonding temperature — or, still worse, the formation of brittle compounds in the interface of nearly all ferrous and nonferrous metals clad with aluminum at 1025 to 1200° F.

Great solubility of one compo-

Sticking Temperatures (°F.)

Metal	Powder Size (Mm.)	Atmosphere		
		Air	Hydrogen	Vacuum
Silver	0.044 to 0.074	295	—	365
Carbonyl iron	—	284	—	410
Copper	>0.074	Variable	590 to 635	698
Copper	0.044 to 0.074	410 to 414	590 to 601	680 to 70
Copper	<0.044	396 to 399	554 to 576	702 to 70

Fig. 3 — Cylindrical Assembly Used for Test Welds and Outline of Test Piece



nent in the other is usually undesirable when certain physical properties like electrical resistance, color or strength have to be kept at predetermined standards. It is fortunate that the rate of diffusion is small in most of these metallic combinations with high solubility; it frequently increases as the solid solubility decreases, as is pointed out on page 311, Vol. I, of Carpenter and Robertson's "Metals". The extremely small solubility between silver and iron is probably accompanied by diffusion at high velocity.

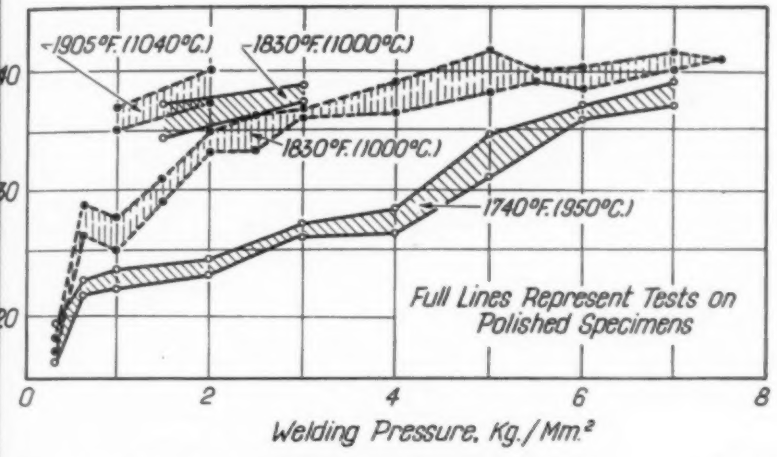


Fig. 4 — Tensile Strength Developed in Copper-to-Steel Pressure Welds, as Pressure Varies. Copper disk was 1 mm. thick; duration of welding was 1 min. 1 kg. per mm.² equals 1420 psi.

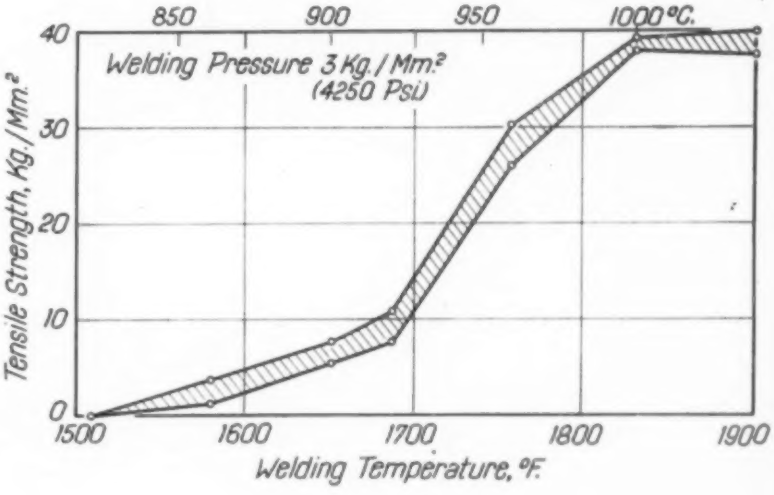
Temperature Versus Pressure — A rather interesting German paper* on solid phase bonding of copper to steel has not been translated and published in this country; hence, a brief description is given here of some of the results. For the experiments 0.20% carbon steel was used and copper with a 0.06% residual phosphorus. Figure 3 illustrates the cylindrical assembly used for the pressure welds; the shaded parts are to be machined off after welding to obtain a tensile test specimen.

The time factor was of little consequence in these tests; between welding times of 1 min. and 2 hr. no difference in weld strength could be determined. Pressure, surface finish, form, plastic conformability, and cleanliness of the interface are named as technical prerequisites of satisfactory pressure bonding. The author emphasizes that these factors are interchangeable to some extent. The truly indispensable factor, however, is the temperature. This is shown in Fig. 4.

On the other hand, Fig. 5 indicates that the pressure can be held low enough to prevent a substantial deformation. This means that geometrically simple-shaped machine elements can be clad with copper or bronze on all surfaces required without appreciable changes in dimensions during the cladding operation.

Outlook — The predominant role of temperature in these German data for the steel-copper combination is a fact on which there can hardly be much controversy. For most other metal combinations, temperature has also been the No. 1 factor; however, the study of the other variables, of which a much too superficial survey has been given here, will indicate that the paramount importance of temperature is mainly due to three basic concepts, one the dispersion of nonmetallic films, the others conformability and diffusion. Since the elimination of surface films is feasible to some extent (a complete elimination is hard to anticipate, in view of the great difficulties of working in vacuum on an industrial scale) the intimacy of contact can be improved. Perfect contact, of course, underlies the above-named three factors. If, under such conditions, temperature and pressure become somewhat more interchangeable than they are now, product and output may improve in numerous metal cladding operations. Such means to prevent or reduce oxide films as the use of reducing atmospheres, fluxes and salt baths have been explored only cursorily — as far as the writer knows. However, more progress in this type of bonding technique can be expected.

Fig. 5 — Tensile Strength of Copper-to-Steel Joints Welded at 4250 Psi. for 1 Min. at Various Temperatures (Engelhardt)



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*"Zur Weiterentwicklung der Plattierung" by Werner Engelhardt, *Zeitschrift für Metallkunde*, January 1942, page 12.

At the photographic exhibit held by the American Society for Testing Materials early in the summer, The Editor noticed some unusual photographs showing the change in appearance of the oil film during the process of metal cleaning. It occurred to him that such visual evidence concerning an obscure operation should lead to practical improvements — as indeed it has — and this article shows how it is effecting savings to the extent of six figures at Frankford Arsenal.

ON THE MECHANISM OF METAL CLEANING

By SAMUEL SPRING and LOUISE F. PEALE
Laboratory Division, Frankford Arsenal, Philadelphia, Pa.

A STUDY has been conducted at Frankford Arsenal of the mechanism of metal cleaning. Direct visual and photographic observations, particularly under the microscope, were made of the process of oil removal from metal. In addition, information obtained during the course of a number of investigations on metal cleaning has been applied to this study. These observations lead to the conclusion that substantial evidence is lacking to substantiate the idea that saponification and emulsification are important primary processes in metal cleaning. This would indicate that many commercial practices based on these hypotheses are faulty and inefficient.

In this article an attempt will be made to point out a few of these practices and to indicate how they may be changed to improve the efficiency of metal cleaning. It is interesting to note that our observations and conclusions tend to confirm the results and the proposed mechanism suggested by British chemists such as Adam and Robinson. Many of their conclusions are contained in the "Symposium on Wetting and Detergency", a book printed by the Chemical Publishing Co. of New York in 1937.

The British chemists were primarily interested in detergency as it relates to washing of tex-

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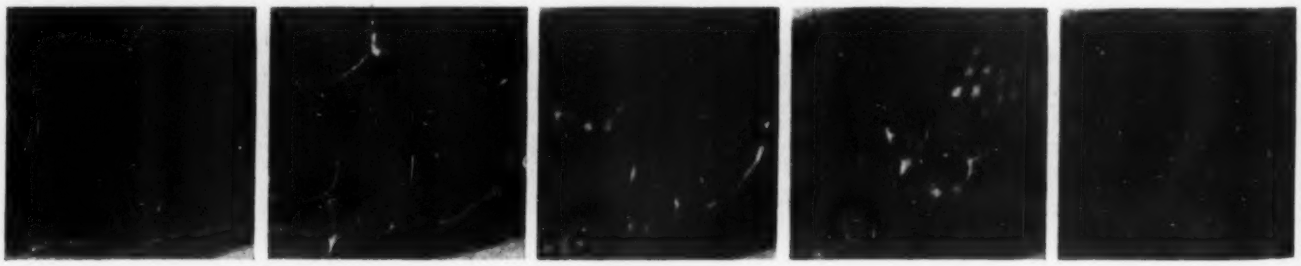
*The authors wish to express their appreciation to Messrs. C. C. Fawcett and E. R. Rechel, Director and Assistant Director of Frankford Arsenal Laboratory for their encouragement, and to the Ordnance Department for permission to publish this paper.



Good Cleaning

2 Min. 3 Min. 4 Min. 5 Min. 10 Min.

Fig. 1 — Changes in the Oil Film During Cleaning; Views Normal to Surface;

Fig. 2 — Changes in the Oil Film During Cleaning; Views Parallel to Oily Surface; Magnification 50 ×

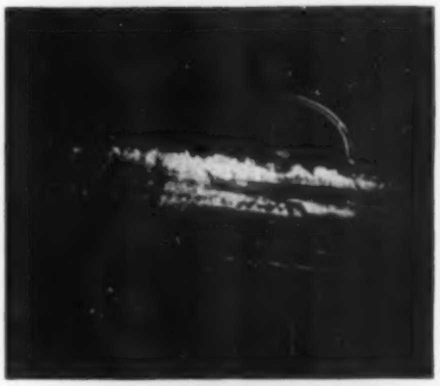
A. Initial stage; contact angle 180°

tiles, but it appears that the mechanism is similar for metal cleaning. Some of our techniques have also been borrowed from these investigators.

The Process of Metal Cleaning — Observations under the microscope have indicated that the removal of oil from metal occurs in a series of stages that may be listed as

1. Shrinkage of the oil film.
2. Expulsion and gathering of much of the oil.
3. Oil globule formation.
4. Removal of the oil globule.

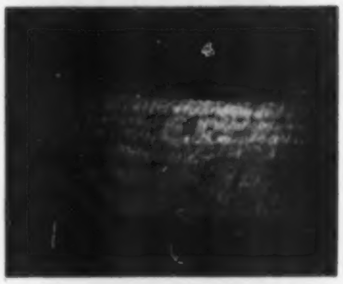
B. Thickening stage; contact angle beginning to change to less than 180°



C (large view). Globule formation; contact angle initially about 90°

These stages are adequately described in the two series of photographs given in Fig. 1 and 2. In the first stage there is a thickening of the oil film which shrinks away from the outside surface. As this process continues, discontinuities occur in the oil film and the gathering of the oil continues outward from these pin-point discontinuities, with further thickening of the oil film in many regions. All the while that this is going on, considerable quantities of oil are escaping from the thickened portions of the oil film. After a large amount of the oil has been thus removed, the remaining oil gathers in isolated pockets which have finger-like projections. These projections steadily continue shrinking until they form discrete globules, which are attached to the metal by a flattened base. This is especially apparent in photograph C of Fig. 2. The final and perhaps most critical stage of the process involves the gradual reduction of the base of the globule so that a perfect sphere is formed, following which the sphere is released from the surface. All of the oil is removed from the surface with the release of the globule — it leaves the surface "chemically clean".

On the basis of the mechanism just described, it becomes easy to see why the viscosity of the oil should be an important factor (Fig. 3, page 104) in determining the efficiency with which it can be removed. In fact, *viscosity* of an oil is a more important factor in its removal than the *thickness* of the oil film. Some data on which this conclusion is based are presented in Table I.

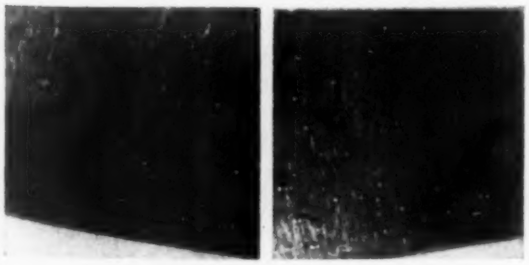


D. Removal of globule; contact angle approaching 0°; area of attachment of oil globule to metal decreasing

E. Removal of globule; contact angle approaching 0°; area of attachment of oil globule to metal decreasing

Poor Cleaning

4 Min. 10 Min.



Magnification 5 ×

In the thickening process, the viscosity of the oil should play a considerable role, since a more viscous oil would tend to flow more slowly and thus thicken less readily. On the other hand, a thicker oil film of the same viscosity is less of a detriment, since much of the oil is ejected from the oil film during the thickening stage.

Table I — Relative Effect of Oil Viscosity and Film Thickness

Viscosity Saybolt at 100° F.	Weight of Oil Film★	Cleaning Index
1 *(a)* 651	0.378	38
(b) 456	0.378	58
2 *(a)* 472	0.278	52
(b) 283	0.278	100
3 *(a)* 472	0.274	53
(b) 283	0.276	91
4 *(a)* 472	0.206	72
(b) 472	0.274	53
(c) 456	0.330	57
5 *(a)* 283	0.276	91
(b) 283	0.252	91
(c) 283	0.159	100
6 *(a)* 472	0.288	56
(b) 472	0.221	64
(c) 472	0.206	72

★Weight of oil film is considered to be roughly proportional to thickness of oil film.

It is interesting to observe the difference in behavior of mineral oil and prime lard oil, containing 1.8% free fatty acid, in the stages of the above-mentioned process. The process of their removal is quite similar but the globules that are formed from lard oil are considerably smaller in size than those from mineral oil and are considerably more flattened at the base. This indicates a stronger bond of attachment between the oil and the metal and manifests itself in considerably less removal of lard oil than mineral oil under similar cleaning conditions. In fact, in the presence of an adequate concentration of an appropriate cleaner, it is easy to cause the globules of mineral oil to become so mobile that they float over the surface, even though they may not be immediately removed from the test panel. During this stage it is possible to remove these globules by agitation. On the other hand, globules of lard oil are neither mobile nor readily removed by agitation.

Saponification and Emulsification

We now wish to point out a number of experimental results, which are easily reconciled with the above understanding of the mechanism of the cleaning process, but fail to support — and in most instances negate — the saponification and emulsification hypotheses. Many of these data were obtained by a method of evaluating metal cleaners developed at Frankford Arsenal and described by Spring, Forman and Peale in *Industrial and Engineering Chemistry* (Analytical Edition) for March 1946, page 201. In this method, panels coated with oil are cleaned in a standard operation in which temperature, time, agitation and other conditions are kept constant. After the standard cleaning and rinsing procedure, the panels are sprayed with water; this condenses droplets of water on those portions of the panel surface that are not clean. A sketch is then made of the oil-covered region on paper that is divided into 100 squares. The percentage of the surface that is cleaned is thus readily obtained. Each value given in the tables is the result of ten observations, the result of experiments on five panels.

A number of experimental conclusions obtained by this procedure tend to refute the idea that cleaning takes place by the chemical reaction of a fatty oil and the cleaner to form soap:

1. Sodium hydroxide is worse than weaker alkalies (Table II) as a cleaner.
2. Mineral oil, which is not saponifiable, requires fairly high alkalinity for its removal.
3. Lard oil, which is saponifiable, is adequately removed by neutral surface-active agents, in contrast with mineral oil which is not adequately removed under this condition (Table II).

In addition, the amount of fat or fatty oil that could be directly saponified by alkaline cleaners as normally used is very small. On the other hand, the free fatty acids in oils that are rich in free fatty acid probably would be saponified, although this would not require very strong alkalies.

Other Observations on Mechanism

It has not been apparent why alkali should be so important in the removal of mineral oil, although its use to assist in emulsification has been mentioned. Some clue as to its true role, which is compatible with the process of metal cleaning herein described, may be obtained by examining some data obtained on the effect of alkaline salts in the water on the interfacial tension between mineral oil and water. These data are presented graphically in Fig. 4.

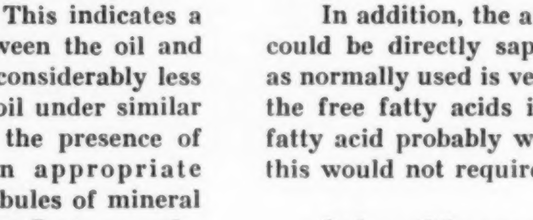


Fig. 3 — Effect of Viscosity (Sec. Saybolt U.V. at 100° F.) of Mineral Oil on Cleaning Index

Table II —
Effect of Alkalinity on Removal of Mineral and Lard Oils

CLEANER*	pH	CLEANING INDEX ON REMOVAL OF	
		MINERAL OIL†	PRIME LARD OIL
1.5% Sodium hydroxide	13.5+	0	0
1.5% Sodium orthosilicate	13.0+	46	41
1.5% Sodium metasilicate	12.5	50	23
1.5% Trisodium phosphate	12.2	27	0
5% Sodium keryl benzene sulphonate	7.0	11	70

*Plus 0.15% sodium keryl benzene sulphonate.
†Viscosity 470 sec. Saybolt 100° F.

These hitherto unpublished data may well serve to clarify part of the mechanism of cleaning. They furnish an explanation of the well-known influence of alkaline salts in cleaning, without assuming that these salts take part in a chemical reaction (saponification) or act as synergists (intensifiers) in emulsification. Since the effect of the alkali is to reduce interfacial tension, which is an important factor in the shrinkage of the oil film and globule formation, it is not necessary to invent other actions for the alkali. This concept also permits an explanation of why surface-active agents, which also reduce interfacial tension, can be substituted for alkaline salts. In addition, it provides some explanation for the poor performance of other alkalies relative to the silicates (Table II), since the silicates were more effective in reducing interfacial tension at low concentrations than the other alkalies (Fig. 4).

The importance of the relationship between the condition of metal surfaces and oil removal, which has been described by the present authors in a previous publication ("Oil Removal by Alkaline Cleaners", *Industrial and Engineering Chemistry*, October 1946, page 1063), also serves as evidence for the process of metal cleaning as described above. In the previous paper we pointed out that the presence or absence of an oxide film on metal surfaces determines to a considerable extent the ease with which the oil can be removed from that surface. This is most probably dependent on the bond between the oil and the metal surface, especially at the globule stage.

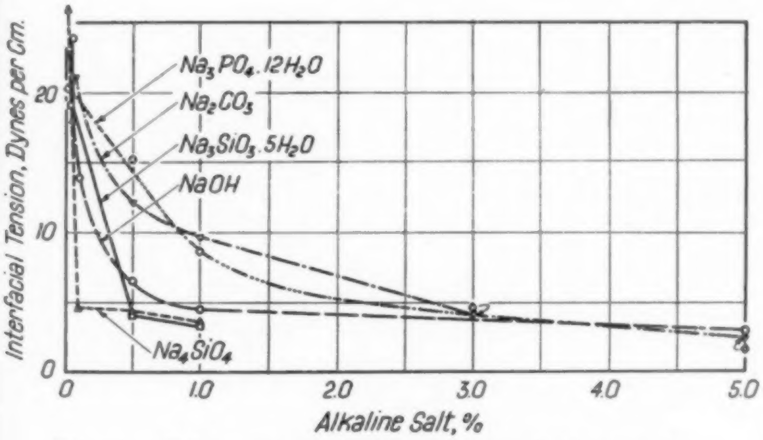


Fig. 4 — Effect of Alkaline Salts in Reducing Interfacial Tension Between Mineral Oil and Water

In the removal of mineral oil from unpickled metal surfaces, the attraction between the oil and metal is reduced by the presence of the oxide film; the globule would then be attached with less rigidity and, consequently, would be removed more readily. On the other hand, pickling removes the oxide film and causes a firmer bond between oil and metal with consequent greater difficulty in removal by the cleaner.

In contrast, fatty oil containing considerable quantities of free fatty acids gives a reverse result — that is, it is removed from surfaces covered with oxide less readily than is mineral oil. Here again, the attraction between the oil and the metal in the globule stage can be used as a basis of explanation. The fatty oils containing free fatty acid would have a tendency to be chemisorbed on the metal because of their potentiality for forming soap with the oxide — in this case, a heavy metal soap. Pickling of the metal surfaces causes the reverse result from that obtained with mineral oil; here it is easier to remove the oil rich in free fatty acid, probably due to the prevention of soap formation.

In addition, the conclusion of the previous paper that increased surface roughness decreases cleaning and with very rough surfaces overshadows the effect of oxide film can be interpreted on the basis of the process described in this article. Thus, increased roughness would increase the difficulty of gathering of the oil film. Past a certain level of roughness, this should prevent oil removal even if other conditions were favorable.

It is difficult to see how the saponification and emulsification hypotheses could be reconciled with the data on the effect of surface conditions. If saponification were the major factor influencing the removal of lard oil, it would be expected that it would be dependent solely on temperature and time conditions and independent of the surface condition of the metal. If emulsification were an important factor it would hardly be expected that the presence of oxide on the surface would change the emulsification process with different oils.

It may also be pointed out that the emulsification concept is also inapplicable insofar as its explanation is based on the prevention of redeposition of the oil. Thus, it has been demonstrated that, after cleaning, mineral oil does not redeposit even though most of it is in such state that it floats to the surface as a thick oil layer.

Practical Applications

The rejection of the saponification hypotheses makes the practice which is widely used of adding larger quantities of alkaline salts or more alkaline salts to cleaning tanks for the purpose of increasing the saponification of oil a rather falacious one. We actually have encountered a situation in which so much alkali was added to the tank that it formed a layer one foot deep on the bottom! This did not result in very much improved cleaning. It is much better to add a surface-active agent which can undercut the oil globule and reduce its attraction for the metal than to attempt to saponify it by the addition of strong alkaline salts. This has been borne out by extensive laboratory and shop tests.

Another widely used commercial practice is based on the emulsification hypothesis: It is assumed that when oil appears on the surface of the bath, the emulsification powers have been lost and it is necessary to change the bath. We have accumulated considerable data in both laboratory and shop to indicate that cleaning, particularly of mineral oil, can be effectively continued so long as the oil is removed from the work, independent of whether a layer of oil is on the surface of the bath or not. It is obvious that by this means the life of cleaning solutions may be considerably increased.

In conclusion, it may be pointed out that it has been possible to effect considerable savings at Frankford Arsenal, the total being about $100,000, merely by the application of the two principles just mentioned, which are based on the process of oil removal described earlier in this paper.

Photo by Shanti Bahadur

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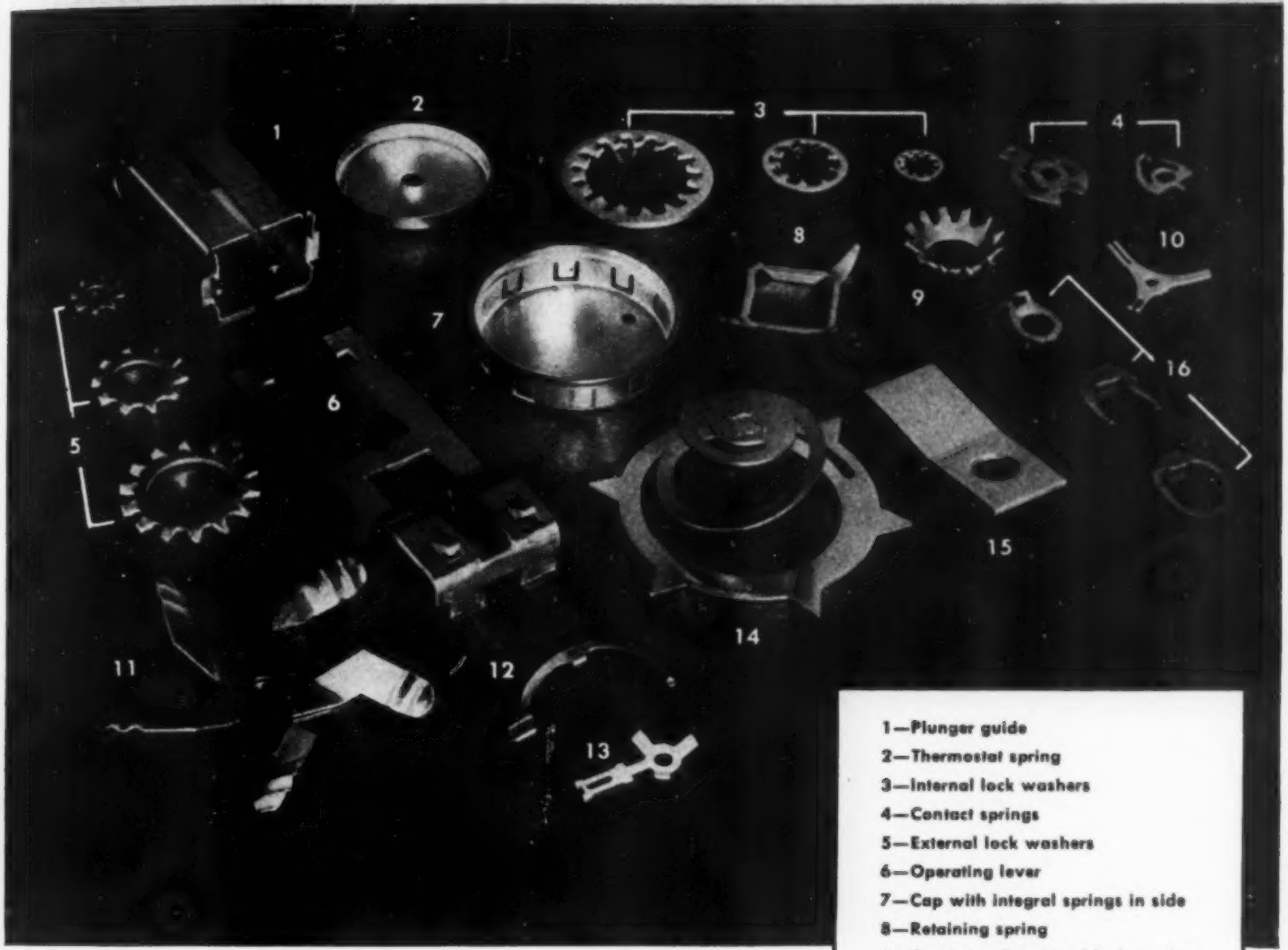

1—Plunger guide
2—Thermostat spring
3—Internal lock washers
4—Contact springs
5—External lock washers
6—Operating lever
7—Cap with integral springs in side
8—Retaining spring
9—Countersunk external lock washer
10—Pressure spring for capacitor
11—Five-contact spring
12—Contact spring for radio part
13—Pressure spring and terminal
14—Involute spring
15—Contact point for solenoid
16—Contact springs
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PERSONALS

E. W. Lovering, formerly supervisor of methods for Revere Copper & Brass, Inc., is now chief metallurgist of the Seymour Manufacturing Co., Seymour, Conn.

D. C. Williams has been recently appointed chief metallurgist of the Addressograph-Multigraph Corp., Cleveland. He was previously chief metallurgist and chemist of Acme & Lees Divisions, Serrick Corp.

William S. Touchman, formerly project engineer at the Antioch Foundry, Delco Remy Division of General Motors Corp., Yellow Springs, Ohio (recently reorganized as Morris Bean and Co.), is now engineer and consultant for Kearney and Trecker Corp., Milwaukee, Wis.

Fred J. Dunkerley, for the past four years a research metallurgist at Battelle Memorial Institute, was recently appointed to the post of assistant professor of metallurgy at the University of Pennsylvania, Philadelphia.

Franklin B. Rote, previously research metallurgist of Wyman-Gordon Co., is now assistant professor of metal processing and metallurgical engineering at the University of Michigan, Ann Arbor, Mich.

Earl B. Douglas, formerly with Standard Steel Spring Co., has been appointed general superintendent of the Flexsteel Division of the National Electric Products Corp., at Ambridge, Pa.

Driver-Harris Co., Harrison, N. J., announces the appointment of **George A. Lennox** as vice-president in charge of sales and **Joseph B. Shelby** as assistant vice-president in the same department.

Robert L. Springer has returned to Vanadium-Alloys Steel Co. as engineer and representative in Chicago. He was formerly with the Rustless Iron & Steel Co. and Geary Stainless Steel Co.

Richard P. Seelig has joined the staff of the American Electro Metal Corp., Yonkers, N. Y. He was formerly connected with Powder Metallurgy Corp., Long Island City.

R. J. Rice, metallurgical and chemical engineer, has been placed in charge of the newly opened Texas technical section of the development and research division, International Nickel Co., Inc.

R. W. Price of the Norton Co. has been appoined district manager of the Connecticut area by the abrasive division.

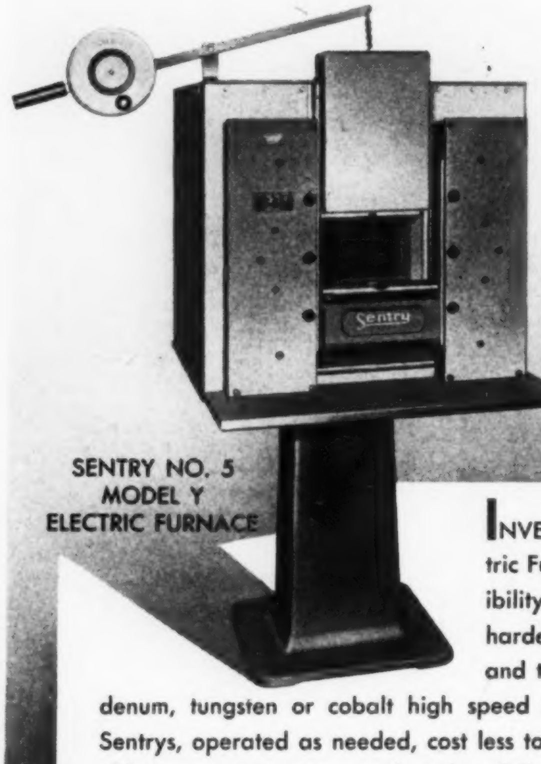
Columbia Tool Steel Co., Chicago, announces the appointment of **George H. Kaiser** as district sales manager at Cleveland. Mr. Kaiser has been with the company since 1930, and from 1942 has been sales manager in Chicago.

John Lang has left New York Shipbuilding Co. to become engineer at the Lukenweld Co.

J. E. Faust is now process metallurgist for the Bridgeport Brass Co., Indianapolis.

B. J. Schier, after 2½ years with Hanford Engineering Works, Richland, Wash., has joined the engineering department of E. I. du Pont de Nemours and Co. at Wilmington, Del.

Carl J. Christensen has left the Bell Telephone Laboratories, Murray Hill, N. J., where he was in charge of metallurgical development of magnetic materials to become dean of the school of Mineral Industries at the University of Utah, Salt Lake City.



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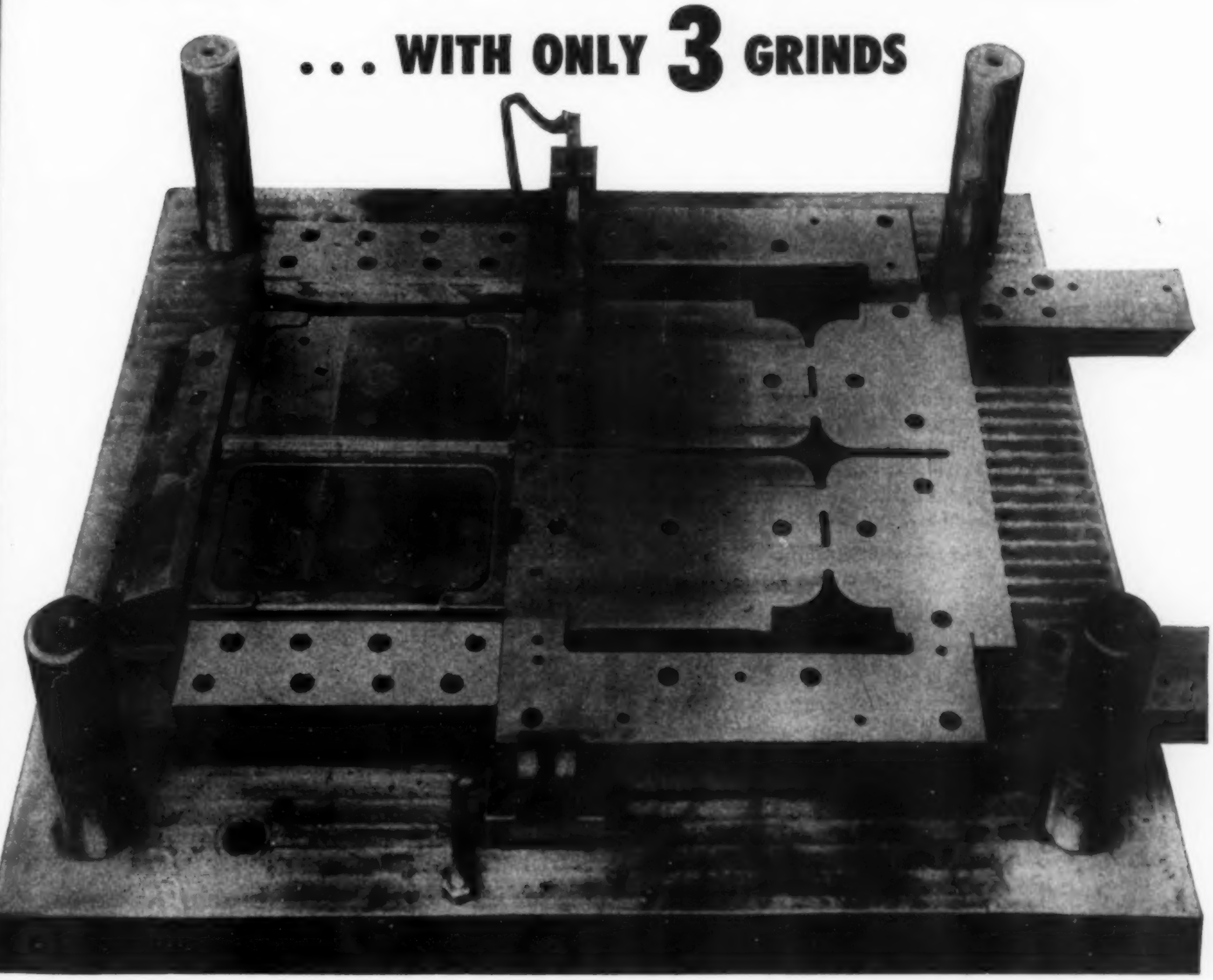

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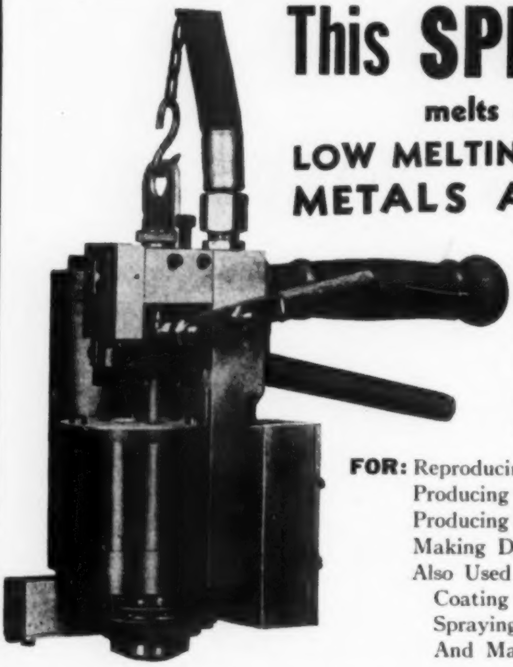

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MS-4

PERSONALS

Martin W. Offinger ⊕, who has recently been engaged in investigating a molybdenite deposit in Cooper, Me., has accepted a position as development engineer in the metallurgical division of the General Electric Co., Pittsfield, Mass.

J. E. Larson ⊕, formerly at the south works of Carnegie-Illinois Steel Corp., has been appointed plant superintendent at plant No. 1 of the Reynolds Metals Co., Louisville, Ky.

E. V. Brown ⊕, formerly with the Curtiss Wright Corp., Propeller Division, is now head of the quality control department for Marmon-Herrington Co., Inc., Indianapolis.

D. G. Pettigrew ⊕ has been transferred by the Whitehead Metal Products Co. to Philadelphia where he will be sales manager. He was previously Baltimore branch manager.

Max E. Tatman ⊕ has returned to Consolidated Vultee Aircraft Corp. as metallurgical engineer for the San Diego, Calif., division.

Formerly metallurgical assistant for Republic Steel Corp. in Detroit, **F. A. Behner** ⊕ has been appointed assistant manager of the claim department in Republic's Cleveland division.

Olaf G. Paasche ⊕ was recently appointed assistant professor of mechanical engineering at Oregon State College, Corvallis, Ore. He was previously metallographer at the Illinois Tool Works, Chicago.

Having received his Ph.D. degree from Lehigh University last June, **Chen-Pao Sun** ⊕ has joined the Universal Trading Corp., a Chinese government purchasing agency, and is doing inspection work at the National Forge & Ordnance Co., Irvine, Warren County, Pa.

H. H. Bliss ⊕, formerly chief chemist of Evansville Ordnance Plant and project engineer at Chrysler Corp., has accepted a teaching post at the University of Oklahoma, Norman, Okla.

E. Portman ⊕, formerly employed as foundry metallurgist by the U. S. Naval Torpedo Station, Newport, R. I., is now associated with the Nassau Smelting and Refining Co., Staten Island, N. Y., as a trouble shooter on customers' foundry problems.

Frank Hicks ⊕ has recently joined the Huck Manufacturing Co., Detroit, as research engineer.

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TRADE-MARK
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TRADE-MARK
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●

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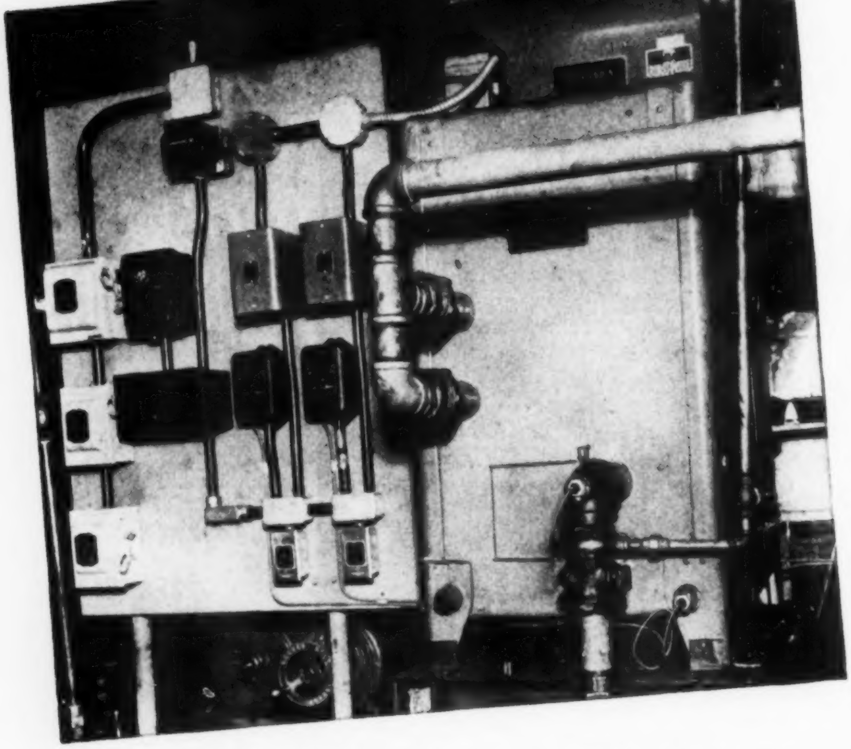

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PERSONALS

Jack Finley ⊕ has been appointed instructor in metallurgical engineering at the University of Washington, Seattle.

Cornelius Elsasser, Jr., ⊕ is now connected with the Self Winding Clock Co., New York, as representative in Cleveland.

Henry F. J. Wilmot ⊕ has been transferred by Shell Oil Co., Inc., to the Chicago division as division engineer in the industrial lubricants department.

Following his discharge from the Army Air Corps, **Sumner S. Smith, Jr.,** ⊕ has joined the Menasco Manufacturing Co. as research analyst.

B. J. Williams ⊕ has returned to the Propeller Division, Curtiss Wright Corp., Caldwell, N. J., as assistant metallurgical engineer after two years in the U. S. Army.

Returning from four years' service in the Navy, **Thomas Watson** ⊕ joined the Philadelphia Gas Works Co., industrial group, and is now supervisor of the division.

Marvin Metzger ⊕ has enrolled at Columbia University, New York City, to pursue his graduate studies in metallurgy. He has recently been discharged from the U. S. Marine Corps.

Seaman Tanenhaus ⊕ has been transferred from the Jeffersonville Quartermaster Depot to the Philadelphia Quartermaster Depot to head the wear resistance section, textile research branch, research and development division.

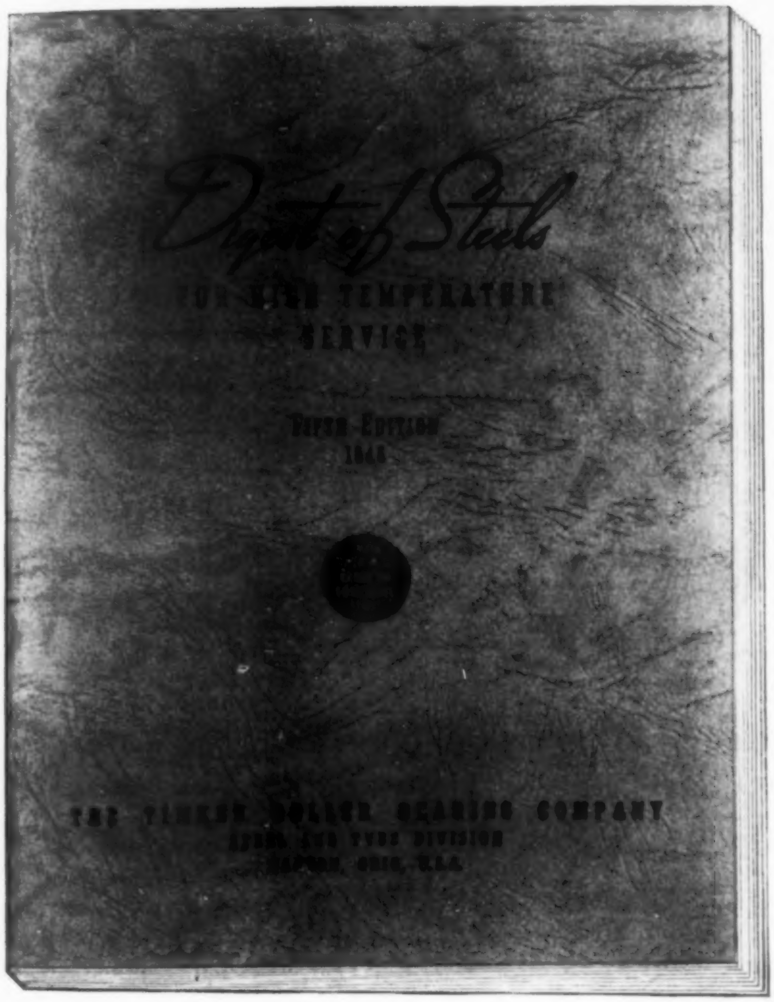
Russell A. Lindberg ⊕ has been employed as a metallurgist with the National Bureau of Standards, Washington, D. C.

Following his release from active duty in the Marine Corps, **Ralph L. Severson** ⊕ has joined the Trafford Foundry, Westinghouse Electric Corp., Trafford, Pa., as manufacturing engineer.

Having completed his graduate studies at Missouri School of Mines and Metallurgy, **Fred H. Bunge** ⊕ has become associated with Armour & Co., Chicago, in the applied research laboratory, chemical division.

William H. Edwards ⊕ has been released from active duty with the Navy and has returned to his former position in the metallurgical research department, Combustion Engineering Co., Chattanooga, Tenn.

Only digest of its kind in the world!



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PERSONALS

Fred Singdale ⊕, formerly with Magnaflux Corp., has joined Mack Manufacturing Co., Plainfield, N. J., as mechanical test engineer in the research division.

Lukens Setel Co. announces the appointment of **Harry A. Dennis** ⊕ as assistant district manager of sales in the Chicago office. He was formerly sales representative in Erie, Pa., and vicinity.

Fred A. Kaufman ⊕, formerly industrial fellow on the McKay Co. fellowship at the Mellon Institute of Industrial Research, has been transferred to the McKay Co. as metallurgical engineer in charge of technical and engineering service in the arc welding electrode division, Pittsburgh.

W. E. Griffiths ⊕, formerly assistant manager of flat rolled steel sales for Allegheny Ludlum Steel Corp., has been elected president of American Alloy, Inc., Chicago, a newly organized corporation.

W. M. Donohoo ⊕, formerly superintendent, heat treating division, M. A. Ford Manufacturing Co., has established his own firm, Donohoo Steel Treating Co., Bettendorf, Iowa.

Ronald Vingoe ⊕, formerly an Army Signal Corps officer, has joined the staff at Battelle Institute, Columbus, Ohio, where he will be engaged in research in steel processing.

Francis B. Nimick, who has been associated with the Colonial Division of Vanadium-Alloys Steel Co. since 1913, has been elected a director of the company to fill the vacancy created by the death of T. H. Childs.

Walter H. Clark ⊕, formerly metallurgist with the Motch and Merryweather Machinery Co., is now connected with the Le Roi Co., Cleveland division, as chief metallurgist.

Announcement is made by the Hungerford Plastics Corp., Murray Hill, N. J., of the election of **R. M. Ellis** ⊕ as vice-president.

Colorado Fuel and Iron Corp., Pueblo, Colo., announces the appointment of **A. F. Franz** ⊕ as vice-president in charge of operations. He had been appointed works manager of the plant last March.

La Salle Steel Co. announces the appointment of **Theodore S. See** ⊕ as first vice-president and general manager and **A. Frank Golick** ⊕ as vice-president in charge of sales.

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for volume forming
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On this 300 ton Warco Eccentric Gear Press, with pneumatic die cushions in bed, Colgate deep draws parts using blanks up to 44" x 70" to a 10" depth.

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To buy the machinery and build the additions to your plant necessary for sheet metal forming, stamping and fabricating would cost—how much? Yet you can add this extra function *without adding to overhead*—by making Colgate your "sheet metal department."

Colgate has complete facilities—up-to-date forming and stamping equipment, experienced labor, and plenty of working space—for the precision manufacture of production parts and even complete units *in quantity*.

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If you have a "tough" assembly to produce in volume, or are merely pressed for time or space, call in Colgate. Specialists in the light metals, and geared for mass-production, Colgate will *deliver the goods* on time (or ahead of schedule) and, more than likely, at a lower cost than you could handle the job if you had a sheet metal department of your own.

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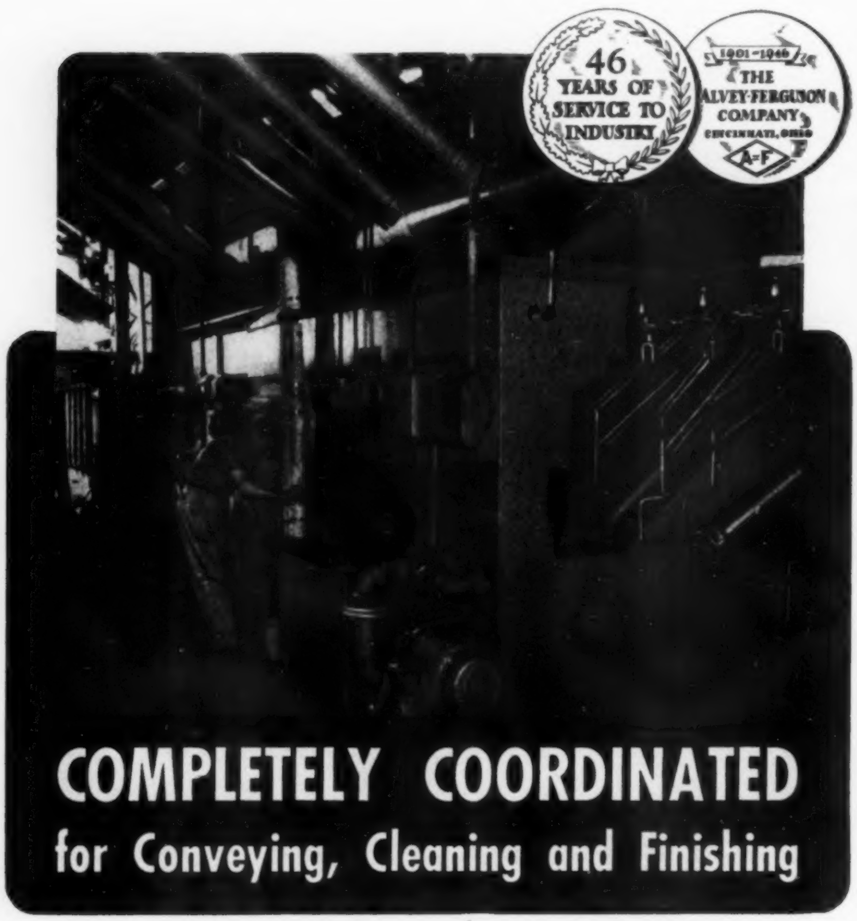
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STEELS AT LOW TEMPERATURES*

A PROJECT to secure and correlate information on the low-temperature behavior of a large number of commercial, wrought and cast, low-alloy steels was intended to clarify low-temperature behavior relating to composition, grain size, heat treatment and hardenability. Ferritic steels show a rather abrupt change in impact tests from a ductile to a brittle fracture as the test temperature is decreased. There is no exact impact level at which the fracture changes sharply from tough to brittle so no arbitrary impact specification can be drawn to differentiate between the types of fracture.

Low-temperature, notched-bar behavior is a very sensitive indication of differences between individual heats that would otherwise be considered duplicates. When information on low-temperature behavior is wanted, it has to be obtained for the individual heats in question.

Considerable differences in notched-bar behavior are met in wrought steels when longitudinal and transverse specimens are compared, the latter results tending to be much lower than the former. These discrepancies are greatest in steels high in nonmetallic inclusions or with banded microstructures. Cast steels, of course, do not show such directional properties. Although cast steels generally show less toughness than the corresponding wrought steels, much of this difference is erased if the values for wrought steel are averaged between longitudinal and transverse specimens.

If enough specimens are tested at enough temperatures and if the fractures as well as the impact values are examined, either the round or V-notch should reveal the pattern of low-temperature behavior. No laboratory bar gives data convertible into impact energy absorbed by an actual part in actual service. Quantitative figures from a notched-bar test therefore do not give a sound basis for engineering design. Single-blow notched-bar test results give

(Cont. on page 130)

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*Abstracted from "Report on Behavior of Ferritic Steels at Low Temperatures", by H. W. Gillett and Francis T. McGuire, Report of the War Metallurgy Committee, published by the American Society for Testing Materials, December 1945, Part I, 55 p.; Part II, 155 p. Both parts $4.00.

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- YOUR BASIC HEAT TREATMENTS CALL FOR CHEAP LARGE-VOLUME ATMOSPHERE GENERATION
- YET . . . OCCASIONAL HIGH-CARBON WORK WOULD BE SENSITIVE TO CO_2 OR H_2O
- AND . . . SPECIAL CARBURIZING JOBS DEMAND ENRICHED ATMOSPHERES

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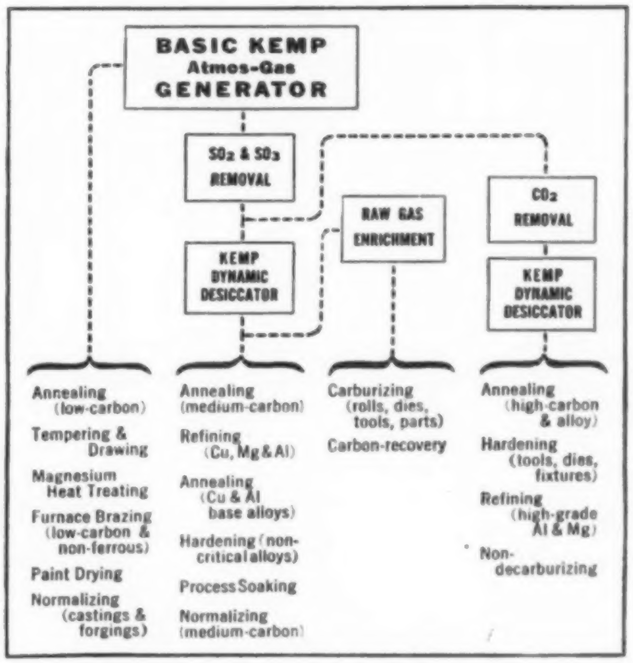
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Solvol and KleenKut, Stuart's water-mixed cutting fluids, while they share in many a machining "miracle," are not "miracle" compounds. They *are* expertly engineered and manufactured products, whose performance is unsurpassed among water-mix, or "soluble" cutting fluids.

Stuart's Solvol, a "super soluble" because of its unusually high cutting quality, will handle jobs beyond the scope of conventional water-mix products, including many so-called all-purpose compounds.

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STEELS AT LOW TEMPERATURES

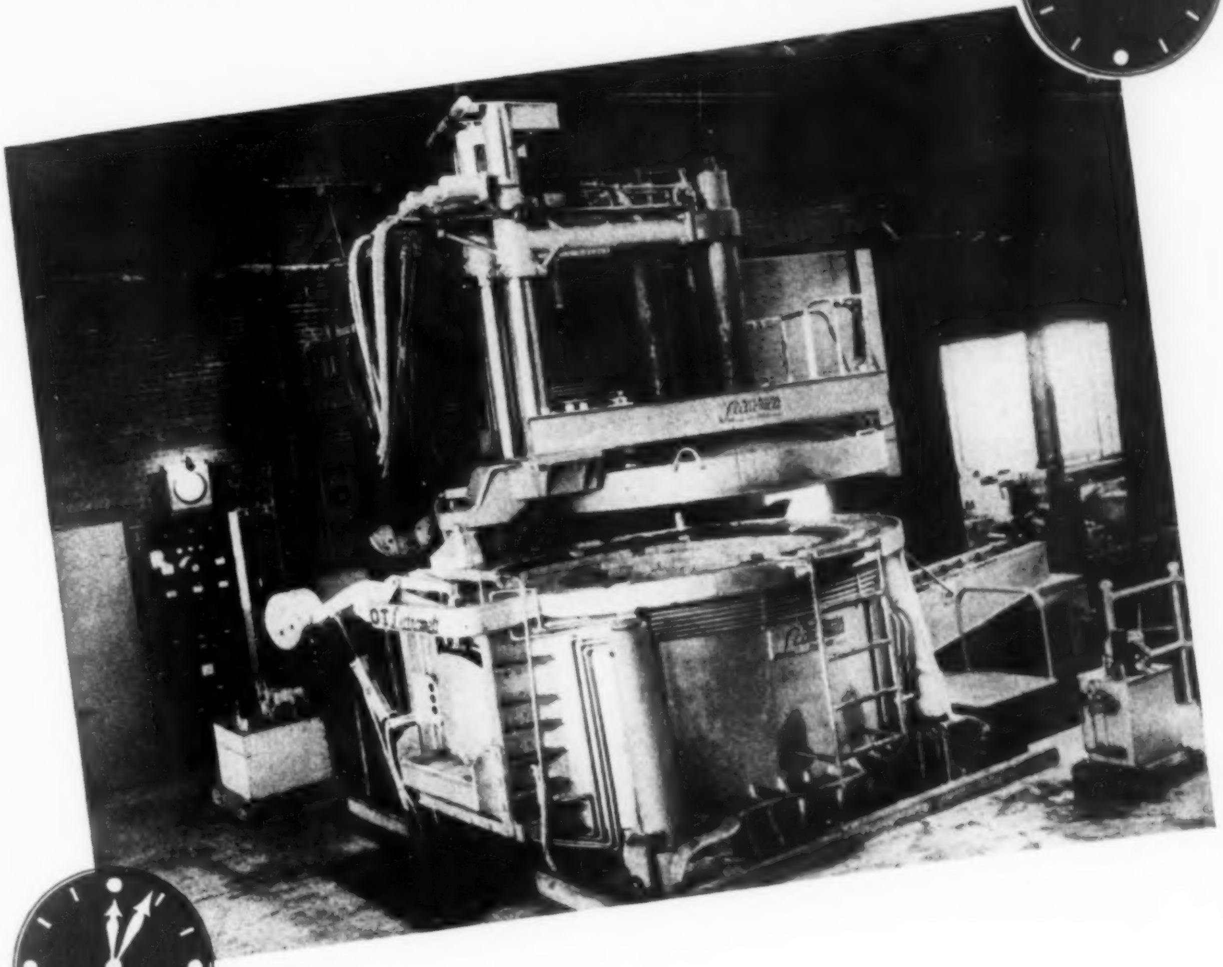
(Cont. from p. 126) no indication of notch sensitivity under repeated stress. Notched-bar tests at low temperatures reveal differences among steels which are not revealed by other mechanical tests.

The production of steels and structures that show tough low-temperature notched-bar behavior is favored by fine grain (actual, not McQuaid-Ehn), by full martensitic quenching and tempering (but neither to extreme softness nor extreme hardness) and by low carbon content. In general, the appearance of bainitic structures during conventional heat treatment, such as occurs in the interior of a large section of a low hardenability steel, is accompanied by inferior low-temperature behavior. Therefore, data obtained on specimens quenched in small sizes should not be accepted as representative of larger sections. Tests on austempered specimens show that, on the whole, austempered medium-carbon alloy steels have poor notched-bar resistance at low temperatures.

Fine grain ordinarily accompanies but may not itself be the direct cause of energy absorption at low temperatures. There is some indication that even though not actually coarsened, a steel heated close to its coarsening temperature may show impaired notched-bar behavior. Fine-grained ferritic steels usually show very much improved low-temperature notched-bar behavior in comparison with similar but coarse-grained steels. Anything leading to a coarse austenitic grain is detrimental. The finer the pearlitic structure obtained at faster cooling rates in normalizing, the better the low-temperature behavior, but if the cooling rate is decreased so that bainite rather than pearlite is produced, poor subzero behavior may result.

No steel studied in the present work has failed to show measurable energy absorption even at −310° F., even if the fracture is of the brittle type. Some fine-grained, fully hardenable steels quenched and tempered have shown 15 to 20 ft-lb., round notch, and tough type fractures at −310° F., together with high static strength. Steels and treatments returning high values at −175° F. are somewhat more plentiful and a good many give high values at −110° F. While the nonquenched steels *(Turn to p. 132)*

MORE TONS PER TURN



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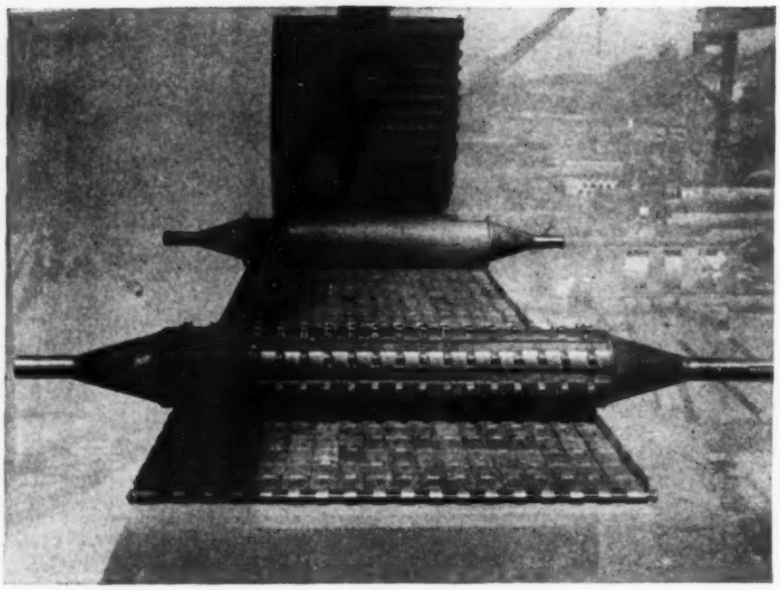

It's a conveyor assembly for a heat-treating furnace, alloyed and cast for a large manufacturer of automobile parts. Perhaps you would be interested in some facts:

Alloying Elements . .	15% Chromium, 35% Nickel
Conveyor Belt	8,400 pounds, statically cast
Head Shaft	1,625 pounds, centrifugally cast
Tail Shaft	804 pounds, centrifugally cast

The belt consists of several thousand individual links assembled and held together by alloy steel rods. No machining of the links was necessary. The lugs on the head shaft were cast integrally with the shaft. The end cones on both shafts were cast statically and then welded on.

You may not need a conveyor for a heat-treating furnace such as this, but if you need *any* high alloy casting—for resisting heat, corrósion or abrasion—we would like to discuss producing it for you. Our experience in static castings goes back to 1922 and in centrifugal castings back to 1931, both pioneering dates.

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STEELS AT LOW TEMPERATURES

(Starts on page 126) **are sensitive to carbon content, the carbon level is not so critical in quenched and tempered steels of medium carbon content. Lower carbon high-alloy steels and higher carbon low-alloy steels, if of equal grain size and hardenability, behave much alike. Nevertheless, even in such steels, those of higher carbon content show a general tendency toward less tough behavior. N.E. steels as a class are as likely to give good low-temperature toughness as are the S.A.E. steels as a class.**

SEGREGATION IN COPPER ALLOYS*

A WIDE RANGE of alloys of the copper-zinc, copper-tin and copper-aluminum systems was prepared using a method of casting into molds designed for the unidirectional solidification of the melt.

Copper-rich alloys of the copper-zinc system are almost free from segregation, but the zinc-rich alloys are prone to segregation of the inverse type, which reaches its maximum in the 15% copper alloy. Two 40% zinc ingots showed rather more segregation in the ingot composed of small equiaxial crystals than in the ingot composed of columnar crystals. In the alloys with high zinc content, reference to the constitution shows that the pronounced inverse segregation is associated with the presence of the eta constituent.

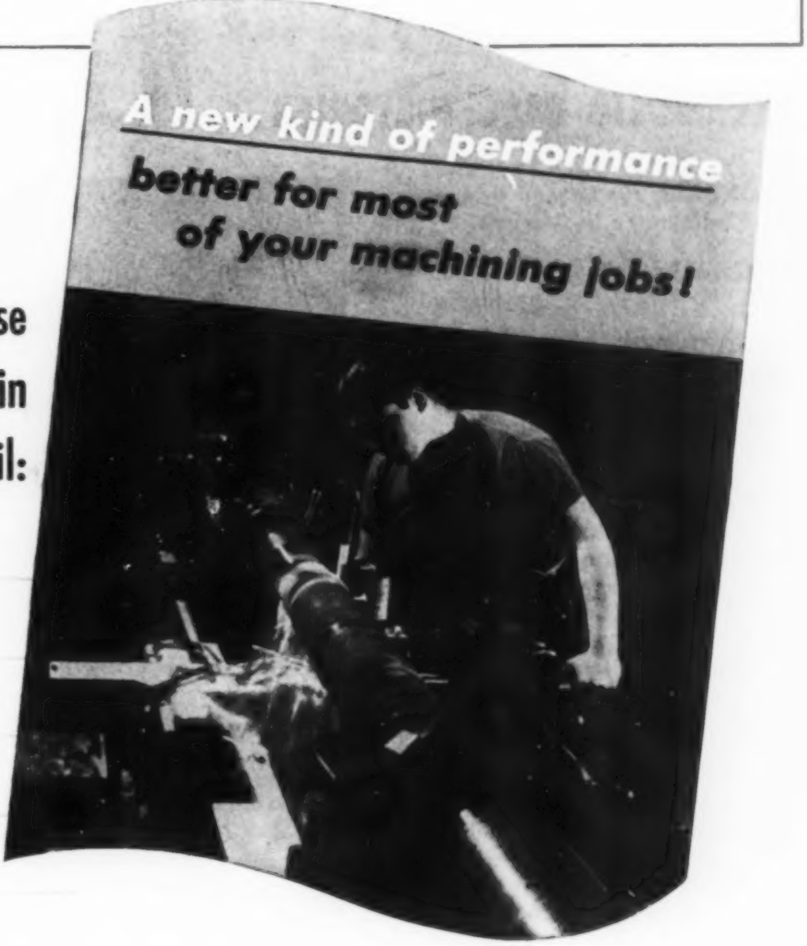
Tests on bled ingots of the 15% copper-zinc alloy show that feeding is more pronounced in the first stages of solidification when the temperature gradient is most steep. With subsequent growth of the ingot, the range of differences of composition is about the same, although, being spread over a greater distance, the composition gradient becomes less steep.

Except for the 0.5% tin alloy, the copper-tin alloys show inverse segregation. The type of segregation can be correlated more readily with the temperature gradient than with the type of crystallization.

(Continued on page 134)

***Abstracted from "The Influence of Macrostructure Upon Segregation", by L. Northcott. *Journal* of the Institute of Metals, V. 72, 1946, p. 31 to 50.**

Announcing the new Gulf Soluble Cutting Oil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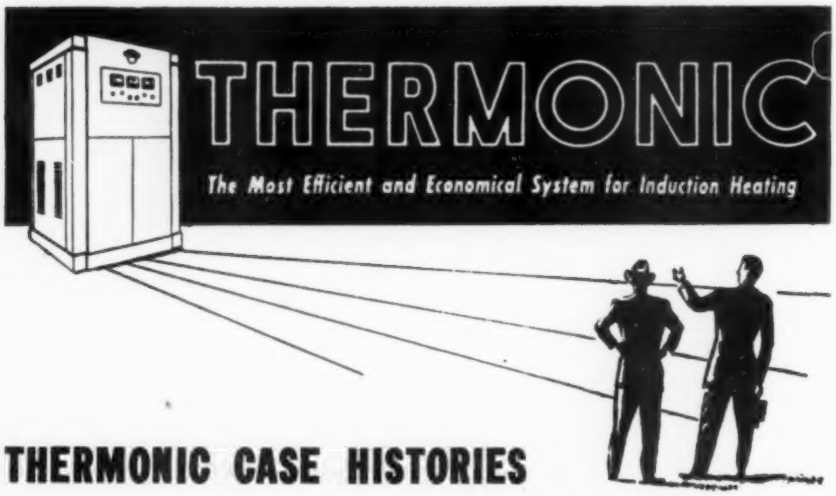
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THERMONIC CASE HISTORIES

PROBLEM: To harden threads on 1″ diameter lead screws.

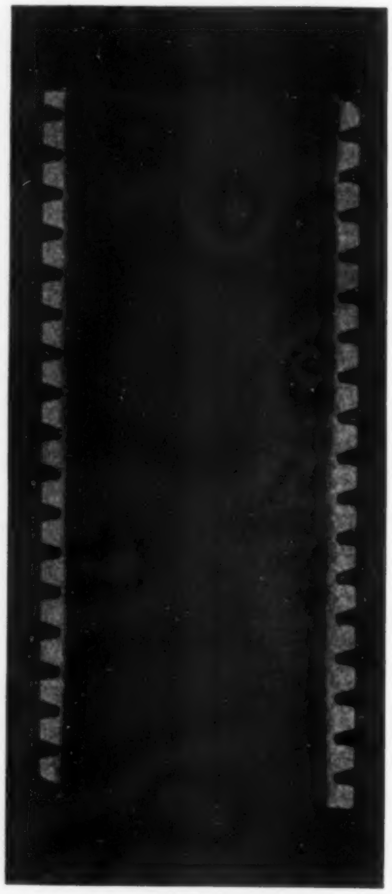
MATERIAL: S. A. E. X-1335 steel.

PRODUCTION RATE: 9″ per minute.

COIL: Multi-turn, cylindrical-type heating coil.

EQUIPMENT: One Model 1070 THER-MONIC Induction Heating Generator; progressive feed fixture and immersion-type oil quench.

REMARKS: Lead screw threads (Acme) are chased on a lathe prior to heat treatment, leaving between 0.020″ and 0.022″ extra stock for final grinding on precision thread grinders. The screw is held in place and aligned by a self-centering chuck. A variable-speed drive motor rotates the screw at 70 R.P.M. and feeds it progressively downward through the heating coil, and into a circulating oil quench immediately below the coil. Hardness obtained on the lead-screw thread section is 52 Rockwell C. (See macrophoto, right.) Lead elongation is limited to a maximum of only 0.0009″ per foot of screw length. Distortion, scale formation and decarburization are negligible.



Longitudinal Section of 1″ Dia., Lead Screw, Showing Induction Hardened Thread Section

●

Photo reproduced through the courtesy of Monarch Machine Tool Co.

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INDUCTION HEATING CORPORATION
389 LAFAYETTE ST. · NEW YORK 3, N. Y.
Largest Producers of Electronic Heat Treating Equipment for Forging
Brazing · Melting · Hardening · Annealing

SEGREGATION IN COPPER ALLOYS

(Continued from page 132)

Tests on bled ingots indicate that normal segregation occurs in the earliest stages of solidification, but at a later stage some action takes place which causes inverse segregation. Since the crystal structure is wholly columnar in both castings, this action must be associated with movement of the tin-rich liquid toward the mold.

Although the copper-aluminum alloys as a whole do not show pronounced segregation, what little there is is mostly of the normal type. Ingots of the 1% aluminum alloy have little segregation, but it is of the inverse type in the ingot with polycolumnar crystals and in ingots with small equiaxial crystals. Segregation is of the normal type in the single-crystal ingot. This fact suggests a possible connection between crystal boundaries and inverse segregation.

Subsequently, tests were made on two bismuth alloys, one with 5% antimony and one with 5% tin. These alloys are known to expand on solidification. The two alloys show pronounced normal segregation.

The existence of a steep temperature gradient is a prime requisite if segregation is to occur. Another essential requirement for segregation, confirmed by the present work, is the existence of a noticeable gap between the liquidus and solidus. Changes in composition in the ingot can generally be correlated with differences in crystal type. For example, the pronounced inverse segregation of the 85% zinc alloy is to some extent associated with the phase changes which this alloy undergoes and which result in an apparent increase in volume, the volume change being connected with the formation of the eta phase.

Consideration of the results in terms of the various theories advanced to account for inverse segregation suggests that only the interdendritic flow theory can adequately account for the differences in composition observed. In its current form, this theory considers inverse segregation to be the result of the contraction which most metals undergo and which leads to the formation of capillaries between the dendrites. These passages then become filled, by capillary attrac-

(Continued on page 138)

Electric Heat to Forge Precision Aircraft Parts

At Thompson Products, Inc. entirely new, highly specialized metallurgical and engineering techniques are being used to produce blades and turbine buckets for modern jet aircraft engines. Made to extremely close tolerances, these wheels must withstand terrific temperature and centrifugal strains in operation. Precision forming of their complex contours in hard-to-work metals calls for an entirely new concept in methods and equipment.

Faced specifically with the problem of forging jet engine blades and turbine buckets to a tolerance of 0.005", Thompson turned to electric heat for the answer.

Equipped with GLOBAR electric heating elements, 60 KW and 100 KW Hayes controlled atmosphere furnaces, as shown here, provide an ideal method. They offer close temperature control, uniform heating of each forging and elimination of scale. Hours of labor are saved. Many grinding and machining operations eliminated. Valuable materials are conserved. Waste is minimized. Costs are reduced to a practical figure.

For micro tolerances of "as forged" parts, GLOBAR equipped furnaces are especially desired. Their many advantages in reducing costs, eliminating waste, and improving product quality make them equally practical in a wide variety of other uses. We welcome the opportunity to discuss your heating problems. No obligation, of course. The Carborundum Company, Globar Division, Niagara Falls, New York.

GLOBAR Heating Elements

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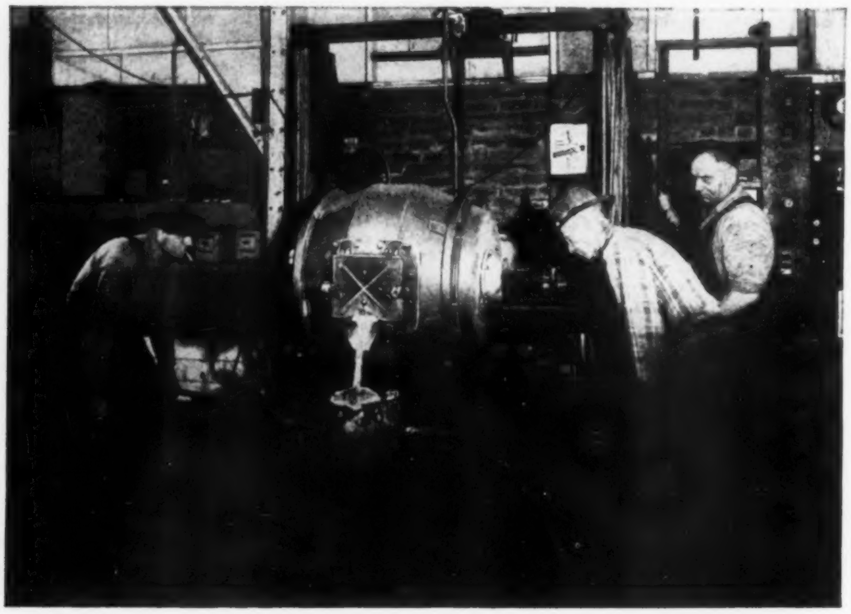
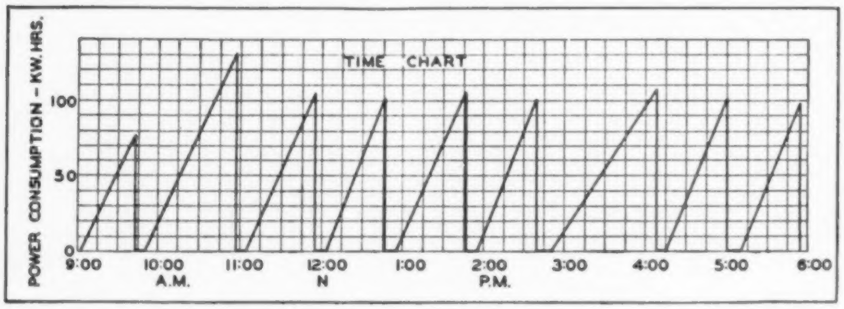
DAILY OPERATING RECORD OF SMALL DETROIT ELECTRIC FURNACE MELTING GREY IRON



DAILY GRAPHIC OPERATING RECORD, TYPE LFC, 350 LB. DETROIT ROCKING ELECTRIC FURNACE, MELTING HIGH QUALITY GREY IRON FOR CYLINDER LINERS.



SUMMARY: HOURS OPERATION 9; NO. HEATS, 8; WT. PER HEAT, 375 LBS.; TOTAL METAL MELTED, 3000 LBS.; KWH TOTAL, 931; KWH PER TON, 620.

Let's take a look at the facts from the daily operating record of a Detroit Rocking Electric Furnace covering a 9-hour working day.

Making high quality grey iron for cylinder liners, from borings, scrap and ferro-alloys, a Type LFC, 350 lb. Detroit Rocking Electric Furnace poured 8 heats in the 9-hour period, each heat weighing 375 lbs., for an output of 3000 lbs. Melting time per heat was 49 minutes; elapsed time per heat, (after the first heat which included preheat period), was 56 minutes. Because the design of Detroit Furnaces permits close control over time, temperature, composition, and other vital melting factors, an engineering product of superior wear resistance is produced. And cost? Consider the low priced raw materials used—consider the quality of the product—and only 620 Kw. hrs. per ton!

Records like this are incontrovertible evidence that Detroit Electric Furnaces are fast melting, economical, efficient. They are your assurance that Detroit Electric Furnaces, installed in your own foundry, will do a faster, more versatile job of melting ferrous and non-ferrous metals. Write for further facts.

DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY • BAY CITY MICHIGAN

SEGREGATION IN COPPER ALLOYS

(Starts on page 132)

tion, with the solute-rich liquid, thus tending to reverse the direction of the segregation which would have occurred. As segregation may occur in ingots composed of small equiaxial crystals, the alternative term "intercrystalline flow" is suggested.

PROPERTIES OF TIN BRONZE*

TIN BRONZES with 2 to 14% tin, degassed by melting under an oxidizing flux (cupric oxide 1 part, fused borax 2 parts and dry sand 2 parts by weight) and deoxidized with 0.075% phosphorus, were poured slowly into small strip ingots. Densities, mechanical properties, and rolling and annealing characteristics were determined and correlated with composition.

The density-composition curve for alloys in the cast condition shows a shallow minimum of 8.88 g. per cc. at 6% tin, corresponding to the maximum freezing range under chill casting conditions. Rolling closes up the slight shrinkage cavities and gives almost theoretical values. Annealing to remove the delta phase causes a slight fall in density in all alloys.

The tensile strength as cast rises steeply from 32,480 psi. for pure copper to 56,000 psi. as the tin content rises to 10%, and then more gradually to 59,360 psi. at 14% tin. The strength must be controlled by structure alone, for these specimens are free from porosity except for minute, harmless, pinhole shrinkage cavities. As a result of increasing amounts of the brittle delta phase, the per cent elongation decreases as the tin content rises, to a minimum of 2% in the 14% tin bronze.

Annealing causes a slight decrease in the tensile strength in alloys with tin contents below 10%. However, the higher tin contents showed an increase to a maximum of 64,960 psi. at 14% tin. The elongation curve for annealed edge

(Continued on page 140)

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*Abstracted from "The Effect of Tin Content on the Properties of Degassed Chill-Cast Tin Bronze", by W. T. Pell-Walpole. *Journal* of the Institute of Metals, V. 72, 1946, p. 19 to 30.

More New Fluorine Compounds by General Chemical

POTASSIUM BIFLUORIDE

KF . HF

POTASSIUM POLYACID FLUORIDE

KF . 3HF

SOME POTENTIAL USES:

HEAT TREATING—Means of controlling the melting point of heat-treating salts.

GLASS—In etching glass or other silicon-bearing products. As "frosting" agents.

CERAMICS—As opacifiers. As materials to increase the fluidity and alter the melting point of the mix.

CHEMICAL PROCESSING Source of HF in dry form. For preparation of elemental fluorine by electrolysis.

ELECTRONICS—Special medium for etching quartz crystals.

MINING—Agents for digestion of insoluble ores.

METALLURGY—As ingredients in fluxes and pastes for welding, brazing or soldering. For surface preparation of aluminum and stainless steel before spot welding.

General Chemical Fluorine Research announces Potassium Bifluoride and Potassium Polyacid Fluoride to American Industry. These are versatile, reactive products whose properties indicate varied applications. For example, consider their potentialities in the fields suggested here.

Perhaps such uses point to a place for either Potassium Bifluoride or Potassium Polyacid Fluoride in *your* development or production program. Experimental samples are available from General Chemical Company, Fluorine Division, 40 Rector Street, New York 6, N. Y., or through the nearest Sales and Technical Service Office.

When writing for the information you need, why not outline your proposed uses for these products? This way the technical experts of our Fluorine Division can work with you toward an early solution of your problem.

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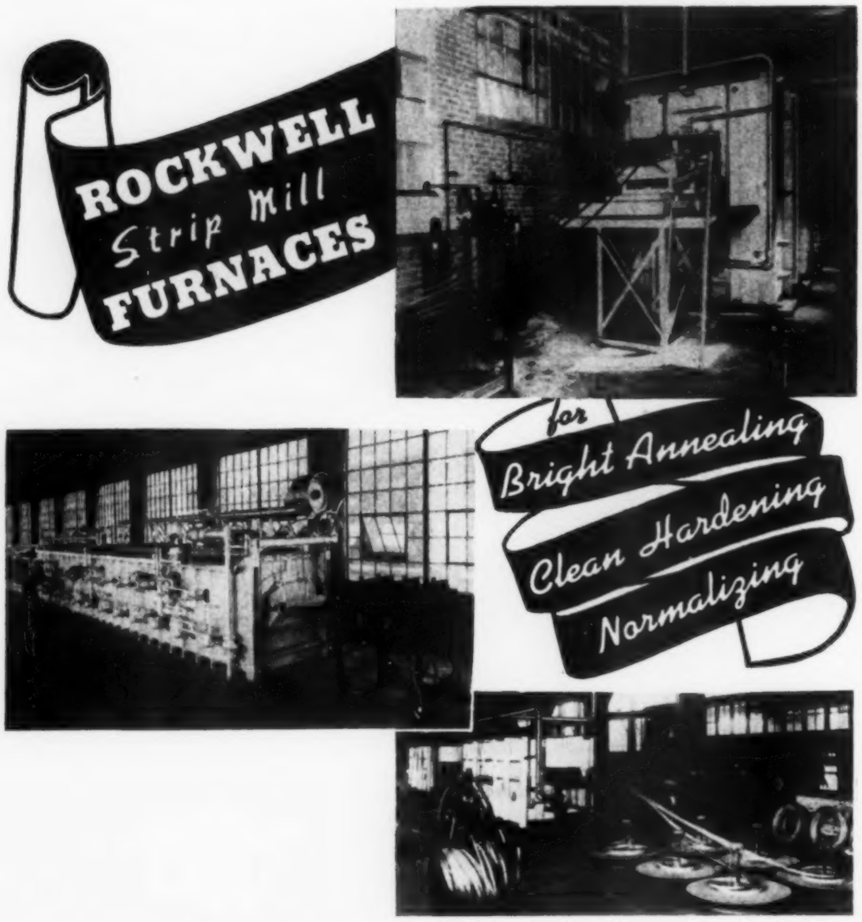

Produce More Uniform Finish and Metal Structure...in Less Time, Space and Equipment...

Top figure shows entrance end of continuous, oil-fired, muffle type furnace for annealing 4 parallel strands of high carbon steel strip without discoloration in a protective atmosphere.

Middle — Gas-fired, continuous, catenary type furnace operating at 1600° to 2000° F. for annealing stainless steel strip.

Bottom — Oil-fired, controlled atmosphere furnaces for continuous hardening, quenching and drawing high carbon steel strip; unreeling stands in foreground.

- For non-ferrous, carbon or stainless steel strip of any width, in quantity from 100 to 15,000 lbs. per hour—
- For clean or bright finish, produced in a controlled furnace atmosphere that eliminates or reduces need for pickling—
- For uniform exposure of multiple strands of strip, moving continuously at precise temperature and rate of heating and cooling—

Rockwell Continuous Furnaces meet specific production conditions as to capacity, character of heat treatment, required surface finish and manner of handling — and save on processing time, material, space and handling.

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Write for Bulletin No. 418

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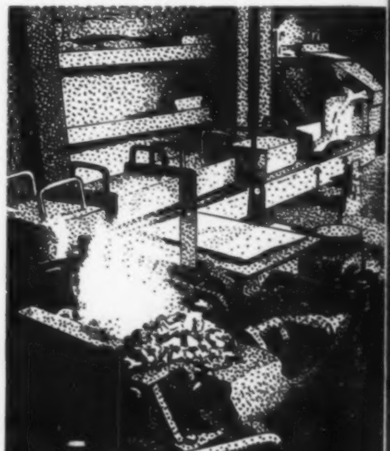
PROPERTIES OF TIN BRONZE

(Continued from page 138)

specimens is approximately horizontal at 50% for tin contents up to 8%, then increases sharply to a maximum of 80% for the 12% tin alloy, falling again to 60% for the 14% tin alloy. Edge specimens have better mechanical properties than specimens from the centers of the ingots, because of the slight shrinkage porosity present in the latter. The Izod impact strength as annealed increases with the tin content to 50 ft-lb. for the alloy with 4 to 8% tin, and then falls gradually to 38 ft-lb. for the 14% tin alloy.

All alloys could be cold rolled to 80% reduction without cracking, but those with over 8% tin could be rolled only after annealing to remove the delta phase. The work hardening capacity of these bronzes as rolled increases regularly with



the tin content up to 8%, then remains constant up to 14% tin. In the hard condition, the tensile strength varies from 100,800 psi. with 4% elongation at 2% tin, to 143,360 psi. with 2% elongation at 14% tin.

The rolled strip of all compositions softened at 570 to 660° F. However, there is a gradual decrease in hardness and strength and an increase in elongation with further increases in the annealing temperature up to 1200° F., probably caused by grain growth. After annealing, the hardness and tensile strength of the strip increase regularly to maximum values with 14% tin, but the elongation reaches a maximum at 10% tin.